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STATE OF MARYLAND WASTE OIL RECOVERY AND REUSE PROGRAM

Edward J. Martin, et al

Environmental Quality Systems, Incorporated

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This report supplements the findings of a 1971 study conducted by the Maryland Environmental Service and the Department of Health and Mental Hygiene, which concluded that the discharge of waste oils to state waters produced a problem within the State of Maryland. The report recommended a comprehensive program of collection, storage, and reprocessing for pollution prevention and for resource recovery. The program was guided by the premises that all categories of waste oils generated within the State were to be managed, recovered, or disposed of, that fuel oils would be the principal products produced, and that current state-of-the-art technology would be used in the design of the program elements.

Using questionnaires and interviews, it was estimated that 18.5 million gallons of waste oils were generated in Maryland in 1972. Mathematical models determined the most effective collection systems and economics for the waste oil program. Preliminary designs were developed for different scales of process plants. Heavy emphasis was placed on protecting the environment. Plant costs varied between $3 million for a 7.3 million gallon per year (mgy) plant, to $7.5 million for a 30 mgy plant. Management, legislative and regulatory approaches to the waste oil problem were also delineated.

A waste oil recovery and reuse program can be initiated immediately using existing technology, collection and storage resources. Because of a need to consider all sources of waste oils, the program requires subsidization at lower plant throughputs. At the 30 mgy capacity, the program economics can be self-sustaining. (EPA)

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STATE OF MARYLAND
WASTE OIL RECOVERY
AND
REUSE PROGRAM

By

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Grant S-800650

Program Element 1BB041

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CONTENTS

Page

Abstract ii

List of Figures iv

List of Tables v

Acknowledgements xi

Sections:

I Conclusions and Recommendations 1

II Introduction 7

III Summary 12

IV Results of Surveys 20

V Waste Oil Collection and Distribution Network 36

VI Preliminary Design Summary 41

VII Costs of System Alternatives 72

VIII Legislative and Program Management Needs 81

IX Implementation Plan 94

X Bibliography.. 104

XI Appendices 107

FIGURES

No.		Page
1	Summary of Waste Oil Recovery and Reuse Program Options	15
2	Five Waste Oil Collection Regions - State of Maryland	21
3	Adsorbent and Solvent Treatment Subsection Schematics	56
4	Incineration Subsection Schematic	58
5	Waste Oil Recovery and Reuse Programs	97
6	Proposed MES Waste Oil Recovery Plant	98
7	Master Zip Code Regions Based on Coast and Geodetic Survey - 100,000 foot grid - State of Maryland	171
8	Industrial Waste Oil Survey Questionnaire	172,173
9	Waste Oil Survey Questionnaire	174
10	Reported Oil Spill and Recovery Incidents - Baltimore Harbor - 7/26/71 - 4/27/73	248

TABLES

No.		Page
1	Waste Oil Sources, 1972	1
2	State of Maryland: Summary of Automotive Waste Oil Survey	22
3	From Crankcase Oil Survey: Collection Costs Reported By Respondees to Questionnaires	23
4	Quantities Based on Survey Results - Industrial Waste Oil -	25
5	Total Annual Volume of Waste Oil as Determined by the Automotive and Industrial Oil Surveys	26
6	From Industrial Oil Survey Collection Costs Reported by Respondees to Questionnaires	26
7	1972 Consumption of Numbers 4, 5, and 6 Fuel Oils by County	29
8	Maryland State Agencies' Fuel Oil Consumption (1972)	30
9	State of Maryland Users by Individual Zip Codes & Prices Paid	31
10	Variations in the Marketing of Automotive Lubes	34
11	Surplus Tankage in the State of Maryland	35
12	Partial Collection System Summary for All Regions	38
13	Waste Oils Generated in Maryland	43
14	1975 Projected Waste Oils	44
15	Potential Waste Oil Re-Refining Unit Processes	47
16	General Unit Process Waste Generation	51
17	Ultimate Disposal Process Alternatives	52
18	Estimated Stream-Day Feed Flows (1975)	60

Tables (Continued)

No.		Page
19	Land Requirements	61
20	Preliminary Capital Cost Estimate for a Full-Scale Waste Oil Recovery Plant	63
21	Process Equipment Costs by Plant Subsection	64,65
22	Preliminary Capital Cost Estimate for a Full-Scale MES Tank Farm	66
23	Summary of MES Waste Oil Processing Facility Tank Requirements	67
24	Preliminary Capital Cost Estimate for a First-Stage MES Waste Oil Recovery Plant	68
25	Preliminary Capital Cost Estimate for a First-Stage MES Tank Farm	69
26	Estimated Stream-Day Product Flows (1975)	70
27	Summary of Cashflow Revenue and Profit Analyses Twenty Alternative System Capacities	76
28	Management Alternatives for a Waste Oil Recovery and Reuse Program	89,90
29	Plant Capacity	99
30	Waste Oil Disposal Alternatives	100 - 102
31	MES Waste Oil Disposal Facility - Product Spectrum ..	103
32	Standard Industrial Classification Categories Receiving Questionnaire	109 - 113
33	Preliminary Capital Cost Estimate for a "Small" MES Waste Oil Recovery Base Plant	121
34	Preliminary Design Net Profit Estimate for a "Small" MES Waste Oil Recovery Base Plant	122, 123

Tables (Continued)

No. Page

35 Removal of Gross Water, Coarse Solids & Other Materials Heavier Than the Oil 125

36 Removal of Water, Solids & Other Materials Heavier Than the Oil 126

37 Removal of Light Ends, Naphtha and Water 127

38 Removal of Acidic Compounds, Additives & Contaminants Stabilized in Solution and Suspension 128

39 Removal of Additives & Contaminants Stabilized in Solution and Suspension 129

40 Separation of Heavy Contaminants Plus Splitting of Oil Into Various Fractions 130

41 Reduction of Nitrogen, Sulfur & Oxygen Contaminants with Hydrogen 131

42 Selective Extraction of Oil and Contaminants 132

43 Adsorption of Metallic Sulfuretted, Chlorinated & Other Additives Plus Odor & Color Bodies 133

44 Removal of Suspended & Settleable Solids From Oil 134

45 Example Process Train 135,136

46 PUP System Numerical Parameters 139

47 PUP System - Totals Over All Regions - Baltimore - 18.0 140

48 PUP System - Totals Over All Regions - Waldorf - 18.0 141

49 PUP System - Totals Over All Regions - Columbia - 18.0 142

Tables (Continued)

No. Page

50 PUP System - Totals Over All Regions - Baltimore - 19.8 143

51 PUP System - Totals Over All Regions - Waldorf - 19.8 144

52 PUP System - Totals Over All Regions - Columbia - 19.8 145

53 PUP System - Totals Over All Regions - Baltimore - 22.0 146

54 PUP System - Totals Over All Regions - Waldorf - 22.0 147

55 PUP System - Totals Over All Regions - Columbia - 22.0 148

56 PIP System Numerical Parameters 149,150

57 PIP System - Totals Over All Regions - Baltimore - 18.0 151

58 PIP System - Totals Over All Regions - Waldorf - 18.0 152

59 PIP System - Totals Over All Regions - Columbia - 18.0 153

60 PIP System - Totals Over All Regions - Baltimore - 19.8 154

61 PIP System - Totals Over All Regions - Waldorf - 19.8 155

62 PIP System - Totals Over All Regions - Columbia - 19.8 156

63 PIP System - Totals Over All Regions - Baltimore - 22.0 157

64 PIP System - Totals Over All Regions - Waldorf - 22.0 158

65 PIP System - Totals Over All Regions - Columbia - 22.0 159

Tables (Continued)

No. Page

66 Unit Cost of Pipeline Waste Oils 162

67 Barge Costs 164

68 Automotive Waste Oil Summary 179

69 Automotive Waste Oil Summary 180

70 Waste Oil Survey Response Frequency 181

71 Industrial Waste Oil Summary 182

72 Industrial Waste Oil Summary 183

73 Table of Symbols for the PUP System .... 197 - 199

74 Table of Symbols for the PIP Collection Network .... 213 - 217

75 Relative Plant Alternative Locations and Distances to Regions 220

76 Summary of Cost, Revenue & Profit (CRP) Model Equations .... 222 - 225

77 Summary of Cash Flow, Revenue & Profit (CRP) Breakeven Price Per Gallon of Product Produced .. 227

78 CRP Model - System Parameters for Case I 228

79 Summary of Cash Flow, Revenue & Profit (CRP) Breakeven Price Per Gallon of Product Produced .. 229

80 CRP Model - System Parameters for Case II 230

81 Summary of Cash Flow, Revenue & Profit (CRP) Breakeven Price Per Gallon of Product Produced .. 231

82 CRP Model - System Parameters for Case III 232

83 Summary of Cash Flow, Revenue & Profit (CRP) Breakeven Price Per Gallon of Product Produced .. 233

84 CRP Model - System Parameters for Case IV 234

Tables (Continued)

No. Page

85 Summary of Cash Flow, Revenue & Profit (CRP) Breakeven Price Per Gallon of Product Produced .. 235

86 CRP Model - System Parameters for Case V 236

87 Summary of Cash Flow, Revenue & Profit (CRP) Breakeven Price Per Gallon of Product Produced .. 237

88 CRP Model - System Parameters for Case VI 238

89 Summary of Cash Flow, Revenue & Profit (CRP) Breakeven Price Per Gallon of Product Produced .. 239

90 CRP Model - System Parameters for Case VII 240

91 Summary of Cash Flow, Revenue & Profit (CRP) Breakeven Price Per Gallon of Product Produced .. 241

92 CRP Model - System Parameters for Case VIII 242

93 Spills of Oily Material to Baltimore Harbor .... 244 - 247

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SECTION I

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

Sources

1. The following are estimates for sources of waste oils generated during 1972 in the given categories based on results of the surveys:

Table 1. WASTE OIL SOURCES, 1972

Waste Crankcase Oils	7 million gallons, annually
Waste Industrial Oils	5 million gallons, annually
Waste Oil from Over-the-Counter Sales	1 million gallons, annually
Waste Variable Oils (Oil Spills, Septic Tanks, and Others)	4 million gallons, annually
Waste Other Oil (Industrial Solvents and Others)	1.5 million gallons, annually
Total Waste Oils	18.5 million gallons, annually

The categories are defined and discussed in the Report (Section IV).

2. The Waste Oil Survey indicated that 27.2 million gallons of lubricating oils and 16.1 million gallons of automotive lubricants were sold in the State of Maryland during 1972. The total of 43.3 million gallons is substantially larger than is indicated by data available from the U. S. Bureau of the Census and the American Petroleum Institute for oil sales in the State of Maryland, even considering any reasonable rate of increase in sales over previous years. Because of the comprehensive nature of the survey which was conducted, estimates based on this survey are considered to be realistic (Section IV).

3. The difference between totals of lubricant sales arrived at by the survey and the data published by the U. S. Census Bureau and the American Petroleum Institute may be due to the method of crediting lubricant sales to the particular states. Maryland obtains lubricating products from sources outside of the State. The converse is probably also true: Some of those lubricant materials accounted for as sales in the State of Maryland are

probably partially utilized in other states. The significance of this conclusion is that data available for oil sales should be used with care in projecting waste oil volumes in other states (Section IV).

4. The amount of waste oil currently being collected and either reused as fuel, reprocessed, or disposed of lies between 6 and 9 million gallons, annually. A significant portion of the collected oil, however, is being reused as fuel or for dust control on roads with little or no preprocessing (Section IV). The remaining amount is improperly disposed of to the land, watercourses, or sewers, or is being incinerated with other solid wastes or industrial wastes.

5. A problem does exist in the State of Maryland with regard to satisfactory collection and disposal of all waste oils generated within the State.

Collection and Storage

6. Between 18 and 22 tank trucks on a full-time utilization basis will be required to operate a State-wide collection network for waste oils. Based upon leasing trucks, the total cost for operating the collection system is likely to be between $300,000 and $450,000, annually, which represents between 1¢ and 3¢ per gallon of waste oil collected, depending upon the efficiency and effectiveness with which the collection system is operated (Section V).

7. It appears that an adequate number of vehicles are available to collect the waste oil generated within the State of Maryland. A collection program can be implemented in the near future based on the capabilities of existing haulers. Use of personnel and trucks maintained by existing haulers will not require purchase or lease of trucks or hiring of additional State personnel by the MES (Section IV).

8. The collection system economics are less sensitive to plant location in terms of annual costs than operating parameters including system overhead, hourly labor wage rates, the rate of utilization of vehicles, and the routes used by the vehicles in collection from individual sources (Section V).

9. In order to minimize the cost of collection, intermediate storage depots are required in all regions except the region in which the central storage and reprocessing facility is located. Requirements for capital expenditures are likely to be about $70,000 for intermediate storage tanks; if new tanks are installed. Capital expenditures are not required if lease-tank storage is used. Storage tank capacity exists in some parts of the State for immediate utilization (Sections IV and V).

10. There is an adequate volume of available storage to meet the immediate needs of the program, including intermediate storage

requirements. However the existing conditions and possible additions which may be required at each available storage location must be identified by surveying each installation (Section IV).

11. There are, currently, no collection mechanisms for handling waste oils from the automobile users who purchase oil over the counter at retail outlets and change crankcase oils themselves.

Processing

12. A plant, using state-of-the-art technology as of early 1973, can be designed and operated for reprocessing waste oils into usable products and for disposing of non-processable oils. The plant process consists of adsorbent treatment, solvent extraction and incineration. The major premise upon which the plant design was based is that all sources of waste oil would be received and that the widest possible range of waste oils would be processed into fuel oil products for use in facilities owned and operated by the State of Maryland. In addition, the plant would have the capability to be modified to produce products of greater value, e.g., lube oil base stock. Ongoing development efforts may modify this conclusion in the future (Section VI).

13. A processing and disposal plant of 22 million gallons per year capacity (design operating base of 300 stream-days per year) will be adequate to meet State of Maryland requirements in 1975 in the event that a total capability for disposal of industrial waste oils is required and complete collection of all waste oil categories is accomplished. Such a plant would cost about $5.7 million (Section VI).

14. A first phase of a total waste oil processing system can be built with a capacity of 10 million gallons per year at a cost of 3 million dollars. It will accept all automotive waste oils, and a portion of the reprocessable industrial oils identified in Conclusion #1. The plant will also have an incinerator to dispose of the residues from the processing plant and about half of the non-processable waste oils. The plant includes batch operation and consists of only those units which can become part of the proposed 20 or 30 million gallon adsorbent treatment, solvent extraction and incineration waste oil recovery system (See Conclusion #12, above).

15. The current technology using vacuum distillation can adequately reprocess "high quality" waste oils. Used alone, this processing approach would lead to large amounts of waste oils being "unprocessable". Also, the preferred product from vacuum distillation is lubricating oil which does not comply with the major design criteria presented in Conclusion #12, above. Accordingly, this process could not be considered for the MES plant design.

16. Acid-clay or caustic-clay treatment processes alone are also inadequate for a total waste oil recovery and reuse program because of

the large quantities of noxious waste residues produced and their limitation to high quality waste oil feed stocks and to lubricating oil products.

Program Financing

17. Sufficient revenues will not be generated by the sale of fuel oil products to sustain either the 10 or the 22 million gallon-per-year operating programs in their entirety. Additional revenues to support the system could be derived from general revenue funds, fees to the motoring public as the user of the service, or as a subsidy to mitigate against pollution from these sources.

18. A fraction of the plant capacity is allocated to processing and disposal of industrial waste oils. The operating and capital costs represented by this fraction can be directly recoverable through the application of fees charged to the industrial users. However, actual experience early in the program is required to identify the cost to each specific source (Section VII).

19. Additional revenues through application of fees probably will not be required for the waste oil recovery and reuse program system financing, provided an additional 8 million gallons per year of reprocessable waste oils could be obtained from surrounding states. (This estimate is based on the 8 million gallons being reprocessable to fuel oil products with minimum waste generation) (Section VII).

Regulations

20. Existing EPA data indicate that the use of waste oils for road oiling has a high potential for producing water pollution problems as a result of runoff. Existing Maryland regulations permit the use of waste oils for road oiling (Section VIII).

21. Maryland does not have lead emission standards. However, direct burning of unprocessed waste oils by large users is carefully controlled by the Bureau of Air Quality Control in the Department of Health and Mental Hygiene (Section VIII).

22. Existing legislation is adequate to initiate a waste oil recovery and reuse program.

23. Existing permit requirements are associated with oil transfer and oil spills and are not completely adequate for all the aspects of a waste oil collection, storage, and reuse program (Section VIII).

Program Implementation

24. The State of Maryland can implement a recovery and reuse program in a step-wise fashion using a combination of existing collection/storage resources, reuse and disposal in Maryland, and waste oil reprocessing in other states in the first phase. Design and

construction of a complete waste oil processing plant can take place in a subsequent phase when experience related to waste oil quantity and quality gained during implementation of the first phase demonstrates the need for such a facility (Section IX).

25. The state-of-the-art which currently exists for the collection, storage, reprocessing, and disposal of waste oils is adequate to permit early implementation of a waste oil recovery and reuse program (State-of-the-Art Report).

26. Although the techniques discussed in this report have been developed for Maryland, they have applicability to other individual states or to several states in concert on a regional basis. In order to extend analyses for collection, storage, processing, and product recovery, data and information related to these program elements to other geographical regions will require reevaluation from the point of view of the area under consideration. Parameters used in the collection and distribution networks and program economics models can be easily modified; when re-run, these models will provide a design basis for other programs.

RECOMMENDATIONS*

1. The first phase of the waste oil recovery and reuse program should be implemented at an early date and consist of the collection, storage, and management aspects. This phase can be implemented without without committing the State of Maryland to construction of a reprocessing plant (Sections VIII and IX).

2. Based on the results of this analysis and other work conducted by the Environmental Protection Agency and other State agencies, the development of waste oil recovery and reuse programs should be initiated on a Nation-wide basis (Sections VII, VIII and IX).

3. Regulations of the State of Maryland should be amended to:

    a) Control the use of unprocessed waste oil for road oiling and dust control purposes;

    b) Control the burning of unprocessed waste oil, in the diluted or undiluted form, as a disposal alternative; and

    c) Revise the existing permit programs for the control of waste oil collection (Section IX).

4. Financial incentives should be considered to encourage private investment in the management and reprocessing phases of the program (Sections VIII and IX).

---

* These are recommendations of Environmental Quality Systems, Inc. to the Maryland Environmental Service.

5. Continued development of unit processes for the re-refining of waste oils is to be encouraged in order to achieve a full-scale applicability to the State-wide and regional programs and verify design parameters using waste oil generated in the State of Maryland (Section VI and the Preliminary Design Report).

6. Separate pricing structures for handling, reprocessing, and disposal of various categories of waste oils should be considered for financing a program including separate fee structures for industrial and other users (Section VIII).

7. Burning tests and evaluations should be conducted by the MES in order to determine the potential of this technique as an alternative, on an interim basis, to reprocessing of waste oils (Sections IX and X).

SECTION II

INTRODUCTION

The importance of developing State-wide and regional waste oil recovery and reuse programs throughout the United States has assumed new dimensions as shortages of petroleum products become more apparent. Even though the total amounts of waste oils available for reprocessing and reuse are relatively small compared to the National sales figures for petroleum products, these amounts could represent a significant fraction of the actual shortages in specific geographic areas.

A report demonstrating that a waste oil problem exists in the State of Maryland was prepared jointly by staff of the Maryland Environmental Service and the Department of Health and Mental Hygiene and published in 1971 (Shields and Miles, 1971). This report concluded:

"1. Oil is one of our most precious natural resources. It is becoming more expensive to purchase in its crude form, transportation accidents foul our oceans, inland waterways and beaches, and this Nation is dependent on long and vulnerable supply lines during times of National emergency.

2. Much of the approximately 25,000,000 gallons of lubricating or manufacturing oils sold in Maryland each year is used only once. Many of the oily dredges from automotive crankcases and industrial plants are indiscriminately discharged to our lands and waters.

3. The available methods of handling used oil, ranging from the most desirable to the least desirable, are as follows:

    a. Re-refining
    b. Burning for Heat Recovery
    c. Incineration
    d. Burning in Place
    e. Disposal on or in the Ground or in Water.

4. The used oil thrown away each year in Maryland amounts to about 45 percent of the new oil sold for lubricating and manufacturing purposes in this State.

5. This used oil can be re-refined to meet specifications for new lubricating oil or reprocessed to meet fuel oil specifications.

6. Reuse of used oil, as either a lubricant or for fuel burning purposes, or both, would significantly reduce:

    a. The dependency of the United States on foreign sources of supply,

    b. Oil spills attributable to tanker and drilling accidents,

    c. The rate of depletion of this valuable natural resource, and

    d. Pollution of our underground waters caused by the indiscriminate dumping of used oil.

7. Maryland Environmental Service should investigate design and implement methods by which oil now thrown away by Maryland's manufacturing plants and automotive service stations can be collected and recycled to be used again as fuel in State-owned institutions and as a lubricant in State-owned vehicles.

8. This program is well worth the investment required for, if it merely breaks even financially in its operation, this pilot project can show how the United States can significantly reduce the pollution problems associated with the production, transportation, and use of oil and, at the same time, nearly double the quantity of lubricating and processing oil available for this Nation's use."

The implementation of a comprehensive WORRP in the State of Maryland can have several desirable benefits:

--- Help alleviate fuel oil shortages during the winter months if products are stored for use during these periods.

--- Eliminate environmental damage to the water, land and air resources of Maryland through use of sound practices for collection, reuse and disposal of oily wastes.

--- Eliminate deliberate high volumes of waste oil spills, and the cost associated with cleaning up these spills, since an alternative would then be available for recovery and/or proper disposal.

--- Prevent waste of a resource by recovering a product which has reuse value.

--- Reduce maintenance costs in sewers and municipal treatment plants incurred due to coating and fouling of equipment by the many, chronic, low volume spills of oily wastes to the waste collection system.

Subsequent to the publication of the report highlighting the waste oil problem, and on the basis of information contained in the report, the Maryland Environmental Service undertook to develop a comprehensive waste oil recovery and reuse system and engaged Environmental Quality Systems, Inc. of Rockville, Maryland to prepare a design for the system, including a preliminary design for a waste oil processing plant based on existing technology which would process a maximum range of waste oil types into the maximum quantity of reusable product, and dispose of the remaining "non-recoverable" fraction such that minimum adverse environmental impact would result.

During the course of the work, it was decided by the MES that the primary products of the plant should be fuel oils. This decision was based on three considerations:

1. Fuel oil products production would alleviate the effect of expected shortages of these materials during the coming heating season;
2. The quantities of fuel oils produced by the reprocessing plant could be directly utilized by State-owned and operated facilities, prisons, hospitals and others; and
3. Fuel oil production would eliminate the need for an extensive marketing program to sell the lubricating oil base stock or blended lubricating oil products. (State requirements for lubricating oil products, i.e., State Roads Commission, Highway Patrol, and other vehicles would represent less than 5 percent of the total potential plant production of such materials).

The development of the WORRP program elements and engineering design was continually guided by several premises. These are:

1. Collection, storage, processing and/or disposal of all types of waste oils, including waste automotive lubricants, industrial waste oils, and others were required. This would ensure protection of water quality and prevention of pollution of watercourses within the State as a result of these materials.

2. Production of the maximum quantity of fuel oil products from waste oils was required while maintaining the flexibility to convert to higher product quality production, i.e., lubricating oil base stocks, at a later date. This would ensure immediate utilization of products as fuel oils during expected reduced supply periods while preserving the potential for recovery of increased revenues during future years.

3. Existing Federal and State water and air quality standards would be met.

4. The use of current state-of-the-art technology was required to ensure that the program could be implemented as rapidly as possible by the State of Maryland without awaiting results of ongoing research and development.

During the course of conduct of this work, a report was completed entitled "Waste Oil Recovery and Reuse -- Summary of the State-of-the-Art, 1972". The report contains data and information related to waste oil quantities in the State of Maryland and National estimates, properties of waste oils and recovered products, a survey of existing laws and regulations for the control of handling and disposal of waste oils, costs and operating data for unit processes available for processing and disposal of oily wastes, and a review of waste oil transport systems. This report was published by the EPA and is available through the Government Printing Office. The information collected during the search of the technical literature, review of ongoing R&D projects, the patent literature, and from existing waste oil rerefineries was used as the basis for the development of the system design for the Maryland Environmental Service.

The data and information resulting from the total project are voluminous. To simplify the presentation of the material, the following format has been selected:

1. The separate report "Waste Oil Recovery and Reuse -- Summary of the State-of-the-Art, 1972", which is described above;

2. This Report, which summarizes the technical data and the various elements of the WORRP, with most of the technical data, mathematical models, and results of analyses contained in several appendices;

3. The separate report entitled "Preliminary Design for a Waste Oil Recovery and Disposal Facility, 1973", describes the basis of design, process selection, and preliminary cost estimates for the process trains selected;

4. Data resulting from the surveys, which is available in a computer printout format;

5. Information resulting from the sensitivity analyses of the collection system and program economics mathematical models, which is available in a computer printout format,

Both the survey data and sensitivity analysis information are available for review at the:

State of Maryland
Department of Natural Resources
Maryland Environmental Service
Tawes State Office Building
Annapolis, Maryland 21401

SECTION III

SUMMARY

THE PROBLEM

The total amount of waste oils produced in the State of Maryland on a yearly basis is estimated to be distributed as follows:

Waste Crankcase Oils -------- 7 million gallons, annually

Waste Industrial Oils ------- 5 million gallons, annually

Waste Oil from Over-the-Counter Sales ------------- 1 million gallons, annually

Waste Variable Oils (Oil Spills, Septic Tanks, and Others) --------------- 4 million gallons, annually

Waste Other Oil (Industrial Solvents and Others) ------ 1.5 million gallons, annually

Total Waste Oils ----- 18.5 million gallons, annually

These estimates are based on questionnaire, survey and interview results (See Section IV).

A problem does exist in the State of Maryland with regard to satisfactory collection and disposal of waste oils. Only about one-third to one-half of the waste oil generated in the State is currently identified as being collected by waste oil haulers. The fate of this oil is uncertain, but a substantial fraction is probably being burned without processing to remove heavy metals as fuel within the State or in other states. A significant amount of the collected oil is also being used for road oiling purposes to control dust. This oil creates a water pollution problem due to runoff. The remaining one-half to two-thirds of the waste oil generated and not identified as being collected by waste oil haulers is being disposed of to the land and water resources of the State, or incinerated as a waste.

The nature of the problem may be characterized as follows:

a) Improved collection, storage, and handling are required to handle between 50 and 67 percent of the waste oil currently generated - between 9 and 12 million gallons per year based on 1972 values - which are not collected and which may be discharged to the environment.

b) Improved processing and disposal techniques are required for most of the waste oil currently generated - between 9 and 17.5 million gallons, annually, based on 1972 values.

Most of the waste oil is generated by industrial, commercial and private users of petroleum products in the Baltimore metropolitan area and in the Baltimore-Washington, D.C. corridor, including Washington, D.C. suburbs in Montgomery and Prince Georges County. Significant amounts are generated in other population centers within the State, including Annapolis, Cumberland, Hagerstown, and Frederick.

Users of petroleum products generate a wide range of waste oils and wastes containing oils which may be characterized as follows:

--- Waste automotive and aeromotive crank case oils which accumulate at automobile service centers, gas stations, bus and trucking centers, and airports.

--- Waste automotive crankcase oils which result from the do-it-yourself oil changes(represented by the so-called over-the-counter oil sales).

--- Waste industrial lubricants such as cutting oils, transformer coolants, equipment lubricants, and others.

--- Oil-water mixtures resulting from clean-up of spills of petroleum products.

--- Variable waste oils resulting from septic tank cleanouts and storage tank bottoms.

--- Oily wastes, largely from industrial operations which contain solvents, paints and other materials.

--- Oily wastes containing small relative amounts of oil such as bilge and ballast water. This latter is considered to be a problem specific to harbor areas and is not considered herein.

THE SOLUTION

The existing waste oil problem in the State of Maryland may be solved by implementation of a phased program consisting of:

Phase I - Implementation with Existing Resources

Collection of all waste oil by existing collections augmented by additional resources, if required.

a) Management of existing waste oil collection services within the State and later extension of services to remote regions.

b) Establishment and management of storage areas at several locations throughout the State preferably by leasing existing storage capacity at tank farms.

c) Establishment and management of a distribution system for the stored waste oil to:

--- environmentally acceptable reuse purposes within the State,

--- rerefining facilities in other States, and

--- disposal at facilities which maintain appropriate water and air pollution control prevention equipment.

Phase II - Permanent Installation

Following accumulation of experience, identification of quantities, and characterization of various waste sources, a permanent program can be initiated that would mix available resources with new processing and disposal facilities within the State to maximize the quantity of waste oil that can be reused. This can be by a combination of private and State investments or by one or the other, exclusively.

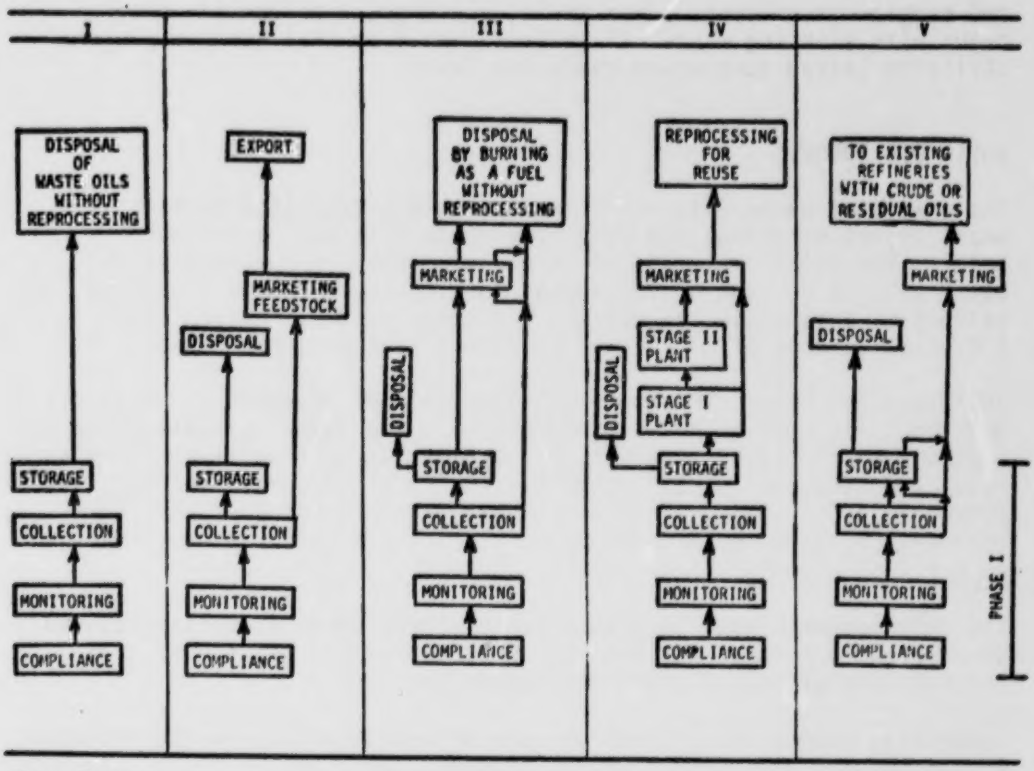
a) Design and construction of a module of a future waste oil recovery and disposal facility of a size and nature to process the types and quantities of waste oils verified by the experience during Phase I. Such a plant would produce fuel oil products primarily.

b) At a later date expansion of the processing plant, if necessary, to accommodate increases in waste oil production during future years, and/or

c) At a later date to produce "higher" reuse products such as lubricating oil base stocks, if a suitable market for such products can be demonstrated.

The alternatives for implementing the waste oil program are presented in Figure 1. All of the alternatives except reprocessing for product recovery are incomplete alternatives in that they address parts of the total waste oil problem, e.g., it is likely that only the high quality waste oils such as waste crankcase oils could be exported to an out-of-state user, or

Figure 1. SUMMARY OF WASTE OIL RECOVERY AND REUSE PROGRAM OPTIONS


I
II
III
IV
V
DISPOSAL OF WASTE OILS WITHOUT REPROCESSING
STORAGE
COLLECTION
MONITORING
COMPLIANCE
EXPORT
MARKETING FEEDSTOCK
DISPOSAL
STORAGE
COLLECTION
MONITORING
COMPLIANCE
DISPOSAL BY BURNING AS A FUEL WITHOUT REPROCESSING
MARKETING
DISPOSAL
STORAGE
COLLECTION
MONITORING
COMPLIANCE
REPROCESSING FOR REUSE
MARKETING
STAGE II PLANT
STAGE I PLANT
DISPOSAL
STORAGE
COLLECTION
MONITORING
COMPLIANCE
TO EXISTING REFINERIES WITH CRUDE OR RESIDUAL OILS
MARKETING
DISPOSAL
STORAGE
COLLECTION
MONITORING
COMPLIANCE
PHASE I

Examples:

Alternative I -- Use of waste oils for road oiling, mixing with refuse to obtain better burning characterisitcs. Incineration of non-useable waste oils.

Alternative II -- Export of recoverable waste oils to existing re-refiners on a toll-fee basis with recovery of an equivalent volume of re-refined products. Incineration of non-recoverable waste oils.

Alternative III -- Diluting waste oils with virgin oils and the mixture used as a fuel oil. Incineration of non-useable waste oils.

Alternative IV -- Re-refining waste oils into fuel oil and lube products. Incineration of non-recoverable waste oils.

Alternative V -- Pretreatment of waste oils or direct dilution with crudes and subsequent refining or mixture with residual oils for subsequent marketing.

burned as a fuel without reprocessing. All of the alternative implementation schemes will require a compliance plan (amended regulations) and program management, a monitoring activity, a collection program begun with existing waste oil haulers, and a partial storage program utilizing leased tank space where available.

WASTE OIL SOURCES

The origin of waste oils is refined petroleum products; however, a small amount of animal and vegetable waste oils may be included in the total. The total amount of waste oil generated in Maryland in 1972 was 5 million gallons of industrial lubricating oils and 7 million gallons of automotive lubricants. To these volumes must be added 1 million gallons of oil resulting from over-the-counter sales.

Additionally, there are about 4 million gallons of variable waste oil and about 1.5 million gallons of "other" waste oil. Variable waste oil includes septic tank cleanouts, oil spills, service station tray cleanouts, and others. "Other" waste oils include industrial solvents and petrochemicals, waste edible oils, waste hydrocarbon process stocks, recovered oil from sewage treatment plants, and miscellaneous waste oils.

The annual growth rate in production of these waste oils is estimated to be about 6 percent nationally. On the average, about half of all lubricant materials sold are for automotive use.

Nationally, about 2.3 billion gallons of petroleum lubricants are used for industrial and automotive applications per annum.

Typical sources of waste oils include automotive service stations and repair facilities, truck repair facilities and depots, aeromotive and marine service facilities, and hundreds of different types of industrial and commercial operations including those using rotary machinery and those using oil directly as a lubricant during processing.

The use of these lubricating materials results in the production of waste lubricant oils. Similarly, in the handling of other oils, such as heating oils, there is a small fraction of the original material which ends up as waste. However, the predominant amount of waste material occurs as a result of replacing used lubricating oils. It is estimated that of all automotive oils sold, approximately 43 percent end up as waste oil. In a similar fashion, industrial oils yield about 18 percent as waste oil which must be disposed of. These values are based on questionnaire results.

During the course of this study a questionnaire survey of sources of waste oil throughout the State of Maryland was conducted. The percentage returns of 41 percent and 24 percent respectively, for the crankcase oil and industrial oil waste sources indicate the success of the survey and the effectiveness of the questions posed. This resulted in the availability of a very broad data base for these two categories.

WASTE OIL CHARACTERISTICS

Waste oils constitute a valuable source of hydrocarbons and have been applied to a variety of uses ranging from road oiling without processing to reuse as high quality lubricants after reprocessing. The conversion potential of waste oils to useful products depends strongly on a number of factors including physical and chemical characteristics.

Waste crankcase oils frequently contain about 5 percent low boiling material originating from the gasoline. Additionally, because of the lead used in gasoline as an anti-knock compound, automotive crankcase oils contain a large amount of lead; up to about one percent by weight. Frequently, 6 to 10 percent of solid materials, sediment, and water are found in waste crankcase oils along with the additives originally compounded into the oil. Insoluble materials in waste crankcase oil include carbon particles, dust, metal particles, metal oxides and other materials. All these contaminants interfere with the use of the spent lubricant for reuse as a lubricant and for other applications, unless the waste oil is reprocessed.

Most waste industrial lubricants contain breakdown products resulting from the use of the oil. In addition, they may contain contaminating materials resulting from the mixing of other waste petroleum products or water solvents, paints, and other materials with the original waste lubricant. Since the virgin lubricant materials usually are compounded with a variety of additives to improve their properties, the waste oils are found to contain fractional concentrations of such additives. Typical additive materials are: zinc and barium compounds, amines, phosphates, sulfonates, sulfides, phosphites, silicons, calcium compounds, polyacrylic polymers, isobutyline polymers, halogens, lead compounds, fatty acids, and phenols.

The characteristics of waste oils are expected to undergo changes in the future. For example, automotive engine lubricants can be expected to become richer in additives to improve their useful life. As a result, waste oils are expected to exhibit a commensurate increase in additives. Over the same period, the removal of lead from gasolines (in accordance with air pollution control objectives established by the Federal government) will result in less lead being found in used crankcase oils. Other metal-containing additives may replace lead-based compounds. In a similar fashion, some changes may be expected in the composition of industrial lubricants with some additional emphasis being given to the introduction of longer-lasting synthetic lubricants. Detailed data and information related to characteristics of waste oils and recovered products can be found in the separate State-of-the-Art Report.

COLLECTION SYSTEM

The State of Maryland was divided into five primary regions -- northwest, north, south, central, and eastern shore -- in order to perform the collection system analysis.

Between 18 and 22 tank trucks of 2800-gallon capacity are required to collect all categories of waste oils and deliver to a central storage location. An additional requirement of between one and three 6000-gallon capacity tank trucks are required to move waste oil between the intermediate storage locations (in all regions except that in which the central storage facility is located) and a central storage location. The cost for collection is about 3¢ per gallon of waste oil delivered to the central location. The location of the central storage facility may affect these collection costs by 15 to 20 percent. However, unfavorable management factors such as overhead, vehicle waiting time, labor wage rates and others, may result in doubling costs. The values for system costs were developed using current rates for truck leasing. However, utilization of existing tank truck haulers to implement the program should be pursued.

With modifications, the collection network models developed may be applied to other states or regional areas in the U.S. and may be used as management assistance tools in the operation of a collection network.

Existing empty storage tank capacity is available and could fill the immediate program needs. However, the condition of the tanks and the need for additional appurtenances will require evaluation of each site. If the existing storage is adequate, a collection, storage, and reuse program could be implemented immediately (Phase I).

PLANT DESIGN

The process train selected for producing fuel oil products from a wide range of waste oil feedstocks includes chemical addition, settling, flash distillation, adsorbent contacting, solvent extraction, filtration, solvent recovery, and incineration. Preliminary designs and cost estimates were prepared using early 1973 state-of-the-art technology for three plant capacities to take into account appropriate program phasing:

Capacity	Estimated Capital Cost
10 million gallons per year	$ 3.0 million
22 million gallons per year	$ 5.7 million
30 million gallons per year	$ 6.6 million

The cost for the 30 million-gallon-per-year plant was determined by scale-up of the preliminary cost estimate for the 22 million gallon facility. Estimates for storage tank requirements are included. About 13 acres of land are required for the 22 million gallon plant including the storage facility. The details of the preliminary design are presented in a separate report, and a complete summary is contained in Section VI of this report.

SECTION IV

RESULTS OF SURVEYS

INTRODUCTION

Knowledge of the quantity and types of waste oils generated is a necessary ingredient to the MES Waste Oil Study since these factors affect the size and design of a system for collection and reprocessing waste oil and the economics associated with the system. One of the techniques employed by the MES Waste Oil Study to obtain such knowledge was through direct survey of potential waste oil generators in Maryland.

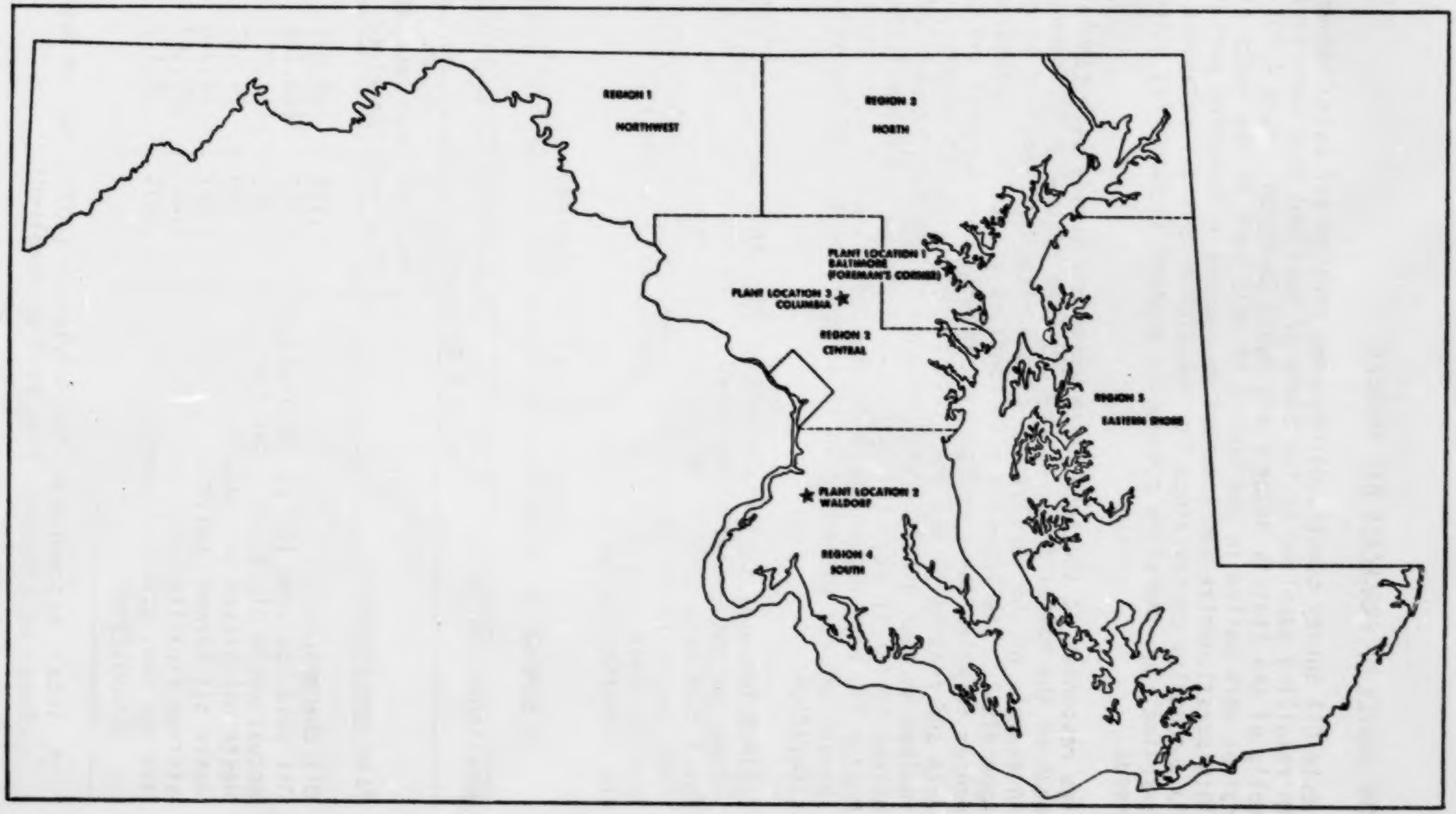
The mail-out questionnaire was chosen as the information-gathering vehicle for the MES Waste Oil Study Survey. Data and information were also obtained through personal contact, telephone calls, and other types of inquiries.

All of the MES Waste Oil Study survey questionnaire forms were forwarded under a covering letter from the Maryland Environmental Service. The content of the questionnaires was subjected to a review process including State and Federal officials. In addition, pilot questionnaires were used to test the reactions of potential recipients before the actual mail-out was performed. The objective of the review and test procedure was to develop questionnaires that would minimize the possibility of misinterpretation. The rate of response was considerably higher than that normally encountered in this type of survey.

Two basic questionnaire forms were employed in the MES Waste Oil Study survey. One questionnaire form was intended for establishments that generated only automotive waste oils. This survey form was mailed exclusively to establishments involved in retailing gasoline. Another questionnaire form was designed to cover a much wider field of waste oil generators, and was mailed to other potential waste oil generators including all Standard Industrial Code classifications except those presented in Appendix A. The crankcase oil and industrial oil questionnaires can be found in Appendix H. Appendix H also includes a discussion of the process for arriving at the five major collection and distribution regions presented in Figure 2. These regions are the basis for the Maryland waste oil collection network. Figure 2 also shows three potential processing plant locations used as examples to test the sensitivity of the model developed to analyze system costs, which are discussed in a later section.

Figure 2. FIVE WASTE OIL COLLECTION REGIONS

STATE OF MARYLAND


REGION 1
NORTHWEST
REGION 2
NORTH
PLANT LOCATION 1
BALTIMORE
(FOREMAN'S CORNER)
PLANT LOCATION 3
COLUMBIA
REGION 3
CENTRAL
REGION 5
EASTERN SHORE
PLANT LOCATION 2
WALDORF
REGION 4
SOUTH

THE SURVEY OF CRANKCASE OIL SOURCES

Waste Oil Survey questionnaires were sent to all establishments engaged in retailing gasoline in the State of Maryland that were listed on the rolls of the State's Motor Fuels Audit Division. Some 4,007 questionnaires were mailed in the course of this part of the waste oil survey. This questionnaire was intended to capture information pertaining only to automotive wastes since its recipients were all retailers of gasoline, and therefore presumably engaged in servicing automotive needs.

The responses to the automotive waste oil survey were tabulated for each of the Master Zip Code Regions (See Figure 7 in Appendix H). An example of the tabulations of the responses received is given in Appendix I. The Appendix also contains a detailed discussion of the manner in which the questionnaire results were handled and complete data and statistics for the State of Maryland. In general, weighted replies to each question were related to the total number of questionnaires mailed in each category. Complete data and statistics for each Master Zip Code Region for both the crankcase oil and industrial oil surveys are not presented in this report because of the volume consideration.

Table 2 includes the data resulting from this survey and extrapolated values for the entire state based on the number of replies received. These data were used to verify estimates made earlier in the study. Final design of the system should utilize these data. Differences between these values and the estimates used in the preliminary design are presented in Section VI.

Table 2. STATE OF MARYLAND:
SUMMARY OF AUTOMOTIVE WASTE OIL MAIL-OUT QUESTIONNAIRE

Questionnaires Sent: 4,077 Questionnaires Returned: 1,675
Percent Returned: 41%

From questionnaire	Number of Replies Received	Amounts from Replies Received	Totals* Extrapolated for Maryland
Oil changes/mo	1,429	68,022	194,000
Oil sold gal./mo (orig. stock usage)	1,393	458,788	1,342,000
Actual waste oil accum. gal./mo	1,360	153,327	460,000
Waste oil picked up gal./mo	935	64,583	282,000
Waste oil burned gal./mo	1,407	12,990	37,600
storage capacity - gal.	1,351	570,147	1,720,000
average max. pickup frequency - pickups/year	876	4,173	19,406

* Totals extrapolated for Maryland = (4077 ÷ No. of Replies Received x Amounts from Replies Received).

About 25 percent of the automotive waste oil generators in the State are paying for collection services (See Table 3). Most of those who pay for the service pay 2¢ per gallon. Some also report payment plans based on a fixed charge per month, fixed charge per "load", and other mechanisms. By far, however, the majority paid nothing at the time of this survey

Table 3. FROM CRANKCASE OIL SURVEY:
COLLECTION COSTS REPORTED BY
RESPONDEES TO QUESTIONNAIRES

PAID by generator $/gallon	No. of replies
0.12	1
0.10	1
0.08	1
0.06	3
0.05	10
0.04	6
0.03	24
0.025	1
0.02	102
0.015	6
0.01	35
0.005	2
ZERO	565
-0.01 (was paid)	1
-0.02 (was paid)	1
Total	759

INDUSTRIAL OIL SURVEY

Because of the more varied and undetermined nature of the sources of industrial waste oil, a different and more comprehensive questionnaire form was used to survey this portion of the population of potential waste oil generators. This questionnaire was sent to all manufacturers listed in the 1971-1972 Directory of Maryland Manufacturers who were likely generators of waste oil. Industrial Waste Oil Survey questionnaires were also sent to all employers listed on the rolls of the Department of Employment and Social Services of the State of Maryland in all industries employing 10 or more persons, except those identified by the Standard Industrial Classification codes listed in Appendix A.

In summary, questionnaires were sent to all establishments that were thought to be significant generators of waste oil, except retail gas stations which were covered in the waste automotive oil survey described above. This resulted in a mailing of some 6,952 Industrial Waste Oil surveys, of which 1,635 were returned, for a response proportion of 23.5 percent. This response was very good since the population addressed was far less homogeneous than in the case of the gasoline tax survey.

Although the tabular format for displaying the results of the industrial oil survey is the same as that used for the crankcase oil survey, a different and more sophisticated statistical technique called stratification was employed to produce these tabulations. This was because the waste oil generation characteristics vary markedly between different Standard Industrial Classification (SIC) codes. That is, toy manufacturers generate far different quantities and types of waste oils than do, say, steel manufacturers. In such a case, stratification of results by SIC codes leads to much more accurate estimates of totals than do simple population treatment techniques such as were used in the crankcase oil survey.

Techniques used for handling and summarizing the data from this survey are presented in Appendix I, along with sample data. Table 4 includes extrapolated values for each industrial waste oil category. The values were arrived at in a manner similar to that shown for the automotive crankcase oil values in Table 2.

An estimated total of 1,480,000 gallons of waste motor oil per year was uncovered in the industrial oil survey. This comes mainly from such sources as bus companies and manufacturing concerns with sizeable transportation fleets that do not retail gasoline and were consequently not covered in the crankcase oil survey.

Table 5 shows the total, combined industrial and crankcase oils as determined by both surveys segregated by collection and distribution regions.

Besides the data presented in Table 6 summarizing collection costs on a dollar per gallon basis, industrial waste oil generators reported payment plans on the following bases:

Collection basis	No. of replies	Reported range
per load	36	$ 5 - 35
per month	10	6 - 50
per year	12	100 - 250
per drum	6	2 - 6

About half of the industrial sources surveyed paid nothing for collection services.

Data collected during this survey should be used during the final design of the waste oil program elements.

Table 4. QUANTITIES BASED ON SURVEY RESULTS

- INDUSTRIAL WASTE OIL -

Questionnaires Sent:	6,952
Questionnaires Returned:	1,635
Percent Returned:	23.5%

From Questionnaire	Totals* Extrapolated for Maryland (gal.)
Oil Consumed/Mo.**	
Gear and Transmission	100,000
Hydraulic Oils	60,000
Water Sol. Cutting	20,000
St. Cutting Oil	75,000
Turbine Oil	1,800
Motor Oil	206,000
Other	1,750,000
TOTAL	2,213,000
Waste Oil Gen./Mo.***	
Gear and Transmission	72,500
Hydraulic Oils	25,000
Water Sol. Cutting	18,000
St. Cutting Oil	11,000
Turbine Oil	5,800
Motor Oil	123,000
Other	287,000
TOTAL	542,000
Waste Reused/Mo.	
Gear and Transmission	350
Hydraulic Oils	1,100
Water Sol. Cutting	35
St. Cutting Oil	46,000
Turbine Oil	----
Motor Oil	350
Other	11,000
TOTAL	59,000
Waste Pickup/Mo.	480,000
Waste Burned/Mo.	114,000
Storage Capacity	1,020,000
Re-Refined Oil Purchased/Mo.	11,000
Maximum Pickups/Year	14,000

* Obtained by multiplying the values received in the questionnaire by the ratio of 6,952 ÷ No. of Replies Received.

** Equivalent to the additional virgin oil needed for makeup.

*** Equivalent to the amount drained and discarded.

Table 5. TOTAL ANNUAL VOLUME OF WASTE OIL AS DETERMINED BY THE AUTOMOTIVE AND INDUSTRIAL OIL SURVEYS

Collection and Distribution Region	Total Volume of Automotive and Industrial Waste Oil Generated per Year	Percentage of Total
1 (Northwest)	1,022,750	8.5
2 (Central)	3,244,680	26.8
3 (North)	6,605,790	54.9
4 (South)	288,780	2.4
5 (Eastern Shore)	890,400	7.4
TOTAL	12,032,400	100.0

Table 6. FROM INDUSTRIAL OIL SURVEY COLLECTION COSTS REPORTED BY RESPONDEES TO QUESTIONNAIRES

Paid by Generator ($/Gallon)	No. Of Replies
0.06	6
0.05	15
0.04	10
0.03	13
0.025	5
0.02	25
0.015	4
0.01	4
ZERO	147
-0.025 (was paid)	1
-0.03 (were paid)	2
TOTAL	232

WASTE OIL FROM OVER-THE-COUNTER SALES

Five large chain merchandising operations with high motor oil over-the-counter sales indicated that their organizations sold an estimated 3,855,250 gallons per year during 1972. This value should account for about 95 percent of such sales. The five organizations sampled were: Western Auto Supply Corporation; Sears, Roebuck and Company; Montgomery Ward and Company; Dart Drug Corporation; and Drug Fair.

On the basis of the crankcase oil survey results, about one-third of the lube oil sold for automotive purposes appears as waste oil. In the case of over-the-counter sales, however, this ratio is probably high since over-the-counter sales represent a significant fraction of oil used for grass-cutter and marine engines, and sales to owners of automobiles with high oil replacement requirements. Using these considerations, the waste oil generated by over-the-counter purchasers is estimated to be 1,000,000 gallons. As service stations are reluctant to accept this type of drainage, it is speculated that do-it-yourself waste oil is disposed of in garbage and refuse pickup or to sewers or land.

WASTE VARIABLE AND OTHER OILS

Interviews with the Metropolitan Sewer Cleaning and Pumping Association of Washington, D.C. indicated additional potential sources of waste oil in the State of Maryland. These sources account for about 200 million gallons of wastewater handled by the Association, annually; tank clean-outs (including waste fuel oils or tank bottoms), service station interceptors, etc., provide this type of oily wastewater. The interviews also indicated that approximately 2 percent of this liquid waste are petroleum products which are currently disposed of with the water. Therefore, the oily wastewaters being handled by the Association will eventually provide an additional 4 million gallons of waste oil for the WORRP facility, assuming strict enforcement of water pollution control regulations. This waste oil estimate was, therefore, included in the system design basis.

The category "Other Waste Oils" includes waste edible oils, waste industrial solvents and sewage treatment plant waste oils. Since the waste oil surveys did not provide information on these materials, the quantity was estimated to be 10 percent of the total volume of crankcase, industrial and variable waste oils.

MARKET SURVEY

Other sections of this report indicate the various types of petroleum products which can be produced through re-refining. Among the most straightforward to produce are the heavier grade fuel oils: Numbers 4, 5, and 6. Since these particular products will be cost-effectively produced, a market survey was performed to determine the number of gallons of residual fuel oils used within the State of Maryland during 1972.

Actual consumption data was sought and trends for future years were determined. Data are presented for all users within the State who use over 700,000 gallons of #4, #5, or #6 fuel oil, per year. More detailed analyses were performed for all State agencies. Major fuel oil distributors were questioned to determine their percentage share of the total market. The results of these activities are presented in this subsection.

Market Size

The total market for fuel oil types #4, #5, and #6 in 1972 exceeded 2 billion gallons. This total consumption figure was obtained from the State of Maryland Department of Health and Mental Hygiene, Bureau of Air Quality Control. The Bureau data derives from a census of all industrial and institutional installations within the State of Maryland. Each installation is examined with regard to air pollution it generates during its normal operations. The Bureau produces a listing of all installations which release more than 25 tons of particulate matter into the atmosphere yearly. A separate indication is made for three categories of activity: processing, fuel burning, and incineration. The listing indicates fuels used. Burning about 700,000 gallons of #4, #5, or #6 fuel oil (or burning other amounts of different kinds of oils or natural gasses) will release 25 tons of particulate matter. Thus, any installation which burns only fuel oil is listed only when the total amount burned exceeds 700,000 gallons; installations which burn other types of fuels in conjunction with fuel oils will be listed if the total particulate matter discharged into the air exceeds the 25-ton limit.

The total market derived from the Bureau of Air Quality Control statistics is summarized in Table 7, distributed by County, indicating Baltimore City separately. Some major State and Federal and local governmental users requirements are included in these totals.

Since not all of the State agencies who use residual fuel oils are listed in Table 7, the total specific requirements of State government users were treated separately.

The General Services Administration of the State of Maryland was queried. This agency procures almost all petroleum products used by State agencies. Once each year, the Agency promulgates a consolidated bidding list indicating all fuel oil required by State institutions. Responses to the bid list provide an overview of the State's internal market, including prices paid for each fuel grade, and turnover (how many times each tank must be filled). Table 8 indicates the total State of Maryland usage by fuel oil type, the number of users of that type, the quantity used during 1972, the turnover, and the average price per gallon.

To obtain some idea of the variation in price paid as related to the total numbers of gallons used and the location within the State, agencies using #5 and #6 fuel oils were examined in detail and listed by Zip Code and by Grade Used. The total of all State agencies was processed to produce a complete listing for use by the Maryland Environmental Service. A summary of that listing is presented in Table 9.

Table 7. 1972 CONSUMPTION OF NUMBERS 4, 5, and 6 FUEL OILS BY COUNTY

County	Use in Gallons
Allegany	30,360,000
Anne Arundel	169,400,000
Baltimore	461,260,000
Calvert	605,000,000
Caroline	1,340,000
Carroll	42,580,000
Cecil	4,000,000
Charles	282,900,000
Dorchester	78,770,000
Frederick	8,300,000
Garrett	40,000
Harford	7,320,000
Howard	4,240,000
Kent	2,900,000
Montgomery	33,760,000
Prince Georges	44,170,000
Queen Anne	220,000
St. Mary's	7,360,000
Somerset	1,160,000
Talbot	1,740,000
Washington	5,910,000
Wicomico	11,620,000
Worcester	3,450,000
Baltimore City	277,280,000
TOTAL	2,085,070,000

Source: State of Maryland, Department of Health and Mental Hygiene, Bureau of Air Quality Control.

Table 8. MARYLAND STATE AGENCIES' FUEL OIL CONSUMPTION (1972)

GRADE	# USERS	QUANTITY USED	TURNOVER*	PRICE($/gal.)
#1	31	82,400	6	.1733
#2	266	13,046,850	8	.1385
#5	6	455,000	6.5	.1239
#6	12	14,383,000	21	.1033

---

* Number of times tanks must be filled each year.

Source: State of Maryland, General Services Administration, Scheduled Procurement Listing.

Table 9. STATE OF MARYLAND USERS BY INDIVIDUAL ZIP CODES & PRICES PAID

ZIP CODE	GALLONS USED	TURNOVER*	PRICE ($/gal)
	Grade #5 Fuel		
20686	150,000	6	.1193
20907	35,000	2	.1054
21208	95,000	12	.1022
21740	30,000	3	.1104
21801	90,000	4	.1704
21856	55,000	7	.1204
TOTAL	455,000 av.	6.5 av.	.1239 av.
	Grade #6 Fuel		
20715	720,000	24	.0972
20740	1,610,000	11.5	.0978
20780	220,000	10	.0978
20794	2,225,000	57	.0942
21112	550,000	17	.0951
21228	3,000,000	15	.0937
21233	1,383,000	28	.0937
21613	600,000	20	.1846
21784	4,100,000	8	.0966
TOTAL	14,358,000 av.	21 av.	.1033 av.

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* Number of times the tanks must be filled each year.

Source: State of Maryland, General Services Administration, Scheduled Procurement Listing.

A complete listing of all State of Maryland users of fuel oil was compiled. These two listings serve to indicate a quite complete list of all potential customers for residual fuels. The two listings produce an apparent market in excess of 2,100,000,000 gallons, annually (primarily of Grade 6 fuel oil).

The market for residual fuels appears likely to expand within the State for two reasons:

1. There is a shortage of Type 2 fuel oil at this time. Therefore, the Department of Health and Mental Hygiene anticipates a switch from Grade 2 to Grade 6 fuel oils on the part of industrial users. Type 6 oil can be burned with appropriate air pollution controls and will produce emission levels which meet the State standards, provided that the new State requirements of 1/2 percent sulfur content for Grades 4, 5, and 6 oils are met.

2. The Department of Health and Mental Hygiene has been reviewing the status of those sources which now burn coal for industrial processes. It plans to order many coal burning operations to convert to oil burning. Normally, this would have caused conversion to Grade 2 fuel burning capability. But it appears likely that conversion to Grade 6 or other residual fuel usage will occur instead.

Thus, to the current market of about 2 billion gallons, will be added a potential market of some 500,000,000 or so gallons by 1975.

It is contemplated that some of the total re-refining capacity will be used for production of lubricating oil from waste oils. Accordingly, this market should not be overlooked.

It appears that the total 1972 sales of motor oil in the State of Maryland was in excess of 20 million gallons, on the basis of questionnaire data and over-the-counter sales.

The State Highway Department has been reported to use about 40,000 gallons per year of auto lubes. The State Police consume about 19,000 gallons per year. Montgomery County reports using about 18,000 gallons per year. Other government organizations using significant amounts of auto lubes are: Maryland National Park and Planning Commission, Washington Suburban Sanitary Commission, Montgomery and other County Boards of Education, State Road Commission and others. But it is clear that the State's share of the total market is likely to be less than 10 percent of the total of 20 million gallons, considering its vehicular ownership.

Thus, some small quantities of re-cycled motor oil produced as a by-product of the refining processes might be used by the States' own vehicles.

Any attempt to recycle the total amount of waste lube oil available from a lube reprocessing facility would result in a requirement to sell a significant fraction in the open market.

DISTRIBUTION SYSTEM SURVEY

The current oil distribution pattern within the State is rather complex. The Maryland Petroleum Institute provided a listing of 17 major oil companies which, it was thought, supplied the bulk of residual fuels burned within the State. Each of these organizations was asked to supply a rough estimate of the total gallonage of Types 4, 5, and 6 residual fuels they sold within the State for 1972. Quantities which could be aggregated from these reports fell far short of the totals indicated by the Department of Health and Mental Hygiene, Bureau of Air Quality Control. Apparently, the differences were made up by a large number of more localized distributors who deal with a less than State-wide market. Contacts with the Oil Heat Dealers of Maryland, and the Maryland Oil Jobbers Council, failed to produce a reasonable gallonage reconciliation with the data provided by the Bureau of Air Quality Control.

Insofar as can be verified, approximately 10 to 15 distributors (in addition to the major oil companies) sell directly to customers within the State. The residual fuels enter the State by pipeline (Colonial and Plantation, an EXXON subsidiary) by barges, and, to a limited extent, by tanker (Steuart Petroleum). The products come from Philadelphia or Wilmington or even from North Carolina and are thus credited as sales to a distribution point not within the State of Maryland.

Inability to detail a distribution network with approximate gallons of sales in each branch leads to examination of the gross market and the analysis of a State re-refinery product distribution plan based on local, municipal and State users.

The size and location of sources of waste oil to be used as feed to the MES-WORRP plant determine, to a large extent, the location of the processing facility. It appears that by far the largest component of waste oil is created by the automotive activity within the State. It also appears from automobile and truck registration data that about 2 million gallons of waste lube oil are produced within the Baltimore metropolitan area, about 2 million gallons within the Washington metropolitan area, about 2 million gallons in the Frederick-Hagerstown-Cumberland region, and 1 million gallons in the rest of the State. Thus, the total waste production from automotive sources approximates 7 million gallons.

The other significant impact on the location of a reprocessing plant is the proximity of the market.

If the City of Baltimore consumption of #4, #5 and #6 fuels is considered by itself, it is clear that all of the total product of the re-refinery can be distributed within that restricted geography -- perhaps even to a single user.

In the marketing of re-refined lubricants, the buyer has traditionally enjoyed a price advantage due to the lower sales price usually associated with re-refined oil products. However, this price spread is strongly dependent on specific marketing conditions, the client, his purchasing power and practices, special requirements of the client, delivery schedules and similar factors. Table 10 illustrates some of the differences found in marketing of lubes.

Table 10. VARIATIONS IN THE MARKETING OF AUTOMOTIVE LUBES

Lube Designation	Customer "A" [¢/gal.	Customer "B" for Virgin	Customer "C" Products]	Typical re-refined commercial oil price schedule [¢/gal.] *
10W-40	96.8	124	69	95
M330Diesel	-	-	57	89
SAE30 Hydraulic oil	-	-	35	65
20W-40	-	69	-	-

The span of prices noted in Table 10 indicates that re-refined products could compete in the market place, providing product acceptability is established.

From this point of view, distribution networks for products appear to be of quite limited interest, and the re-refinery location should be chosen to minimize collection costs and re-refinery economics.

TANKAGE SURVEY

Existing storage tankage not in use because of changes in business climate, new requirements or other factors represent surplus capacity which could be used within the collection network. A partial list of such facilities is shown below in Table 11.

Some of these facilities may require retro-fitting with dike aprons, interceptors and other devices to make them conform to new State pollution control regulations. An evaluation of requirements for modification should be made during implementation of Phase I.

Table 11. SURPLUS TANKAGE IN THE STATE OF MARYLAND

Location	Number of Tanks	Total Volume (Gals.)	Proprietorship Data
Cumberland	5	100,000	Old Exxon bulk plant
Crisfield	Unknown	80,000	Tawes Bros., an Exxon bulk plant
Gambrills	2	40,000	Unknown
Pcocmoke City	2	40,000	Unknown
Frederick	1	60,000	Blue Ridge Oil Co., F. Higganbotham
Baltimore City	5 or 6	15,000,000	Formerly Gulf Oil Co., now under option
	Total Available Storage	15,320,000	

SECTION V

WASTE OIL COLLECTION AND DISTRIBUTION NETWORK

After having divided the State into master zip code areas and then into the five control regions: Northwest, North, South, Central, and Eastern Shore (Figure 2), the PIP and PUP models were applied to the entire State to evolve alternative collection systems and their attendant costs.

The PickUp to Plant (PUP) system employs local collection vehicles which are to pick up waste oil from the sources and deliver it to the reprocessing plant. The basic PUP collection vehicle is a 2,800-gallon tank truck. This size truck is in common use for collection of waste materials from local sources and has the advantage of being able to easily maneuver in and out of small parking lots such as those encountered in service stations, and it is relatively easy to handle in congested traffic.

The Pickup to Intermediate Storage to Plant (PIP) system utilizes 2,800-gallon capacity vehicles for local collection of waste oil within predetermined geographical regions and delivering of the waste to intermediate storage tanks located within the region or in another region. Six-thousand-gallon long haul tractor-trailer combinations, with extra trailers to maximize their utilization, would be used to deliver the oil from the intermediate storage sites to the plant.

Both the collection and distribution models are presented in Appendix J. Both collection models were run for all five regions with the following sets of parameter variations:

1. Three different plant locations: these locations were at Baltimore (Foreman's Corner on the western shore of the Chesapeake Bay), Waldorf, Maryland and Columbia, Maryland. The sites at Waldorf and Columbia were chosen, not because they represent actual potential site locations, but in order to disturb the model sufficiently to determine the sensitivity to cost of wide variations in plant locations. The regional names, location coordinates and distances to the three plant locations are presented in Appendix J. The location coordinates used are those from standard U. S. Geological Survey 100,000-foot grid coordinates.

2. Three plant capacity values were chosen, namely, 18 million, 19.8 million and 22 million gallons per year distributed around the nominal 20 million-gallon-per-year plant size.

3. Three sets of numerical parameters for both PIP and PUP were chosen to represent the expected "Best", "Worst" and "Good" values for running the models. These ranges are expected to represent actual ranges in practice as the collection system is operated throughout the State. The numerical parameters for the PUP system are presented in Appendix J. Those numerical parameters chosen to represent the same spread for the PIP system are also presented in Appendix J.

As might be expected, the bulk of waste oil is generated in Region 2, which encompasses the Washington metropolitan area, and Region 3, which includes Baltimore. The density of waste oil sources in Region 4 is low and it should be serviced by vehicles based in Region 2. Region 5, Maryland's Eastern Shore region, also has comparatively low concentrations of waste oil sources but is treated separately because of its geographical isolation.

In applying the PIP and PUP models to the MES waste oil system, it was assumed that all collection and hauling vehicles were leased rather than purchased. This assumption does not change the basic form of the model. The cost of a vehicle is still represented as a fixed cost depending on vehicle type and a variable cost which depends both on vehicle type and use mileage. The leasing assumption results in no capital investment cost and a somewhat higher fixed charge than would be the case with owned vehicles. Although the impact on overall cost is minimal, the collection models can be run using typical cost value figures for owned vehicles.

All results obtained by running the PIP and PUP models are summarized in the 20 tables of data in Appendix E. Tables 46 through 55 are PUP results, and Tables 56 through 65 are PIP results. The runs illustrated that the most economic situation was had by using a PIP-type system in all the regions except that region in which the plant was located. In other words, it is likely that intermediate storage tanks and long-haul trucks would be used for the four regions removed from the plant location, and the PUP system was most economical for the region in which the plant was located by the model. To summarize, for the case of the plant location at Baltimore (Foreman's Corner), the PUP system should be used to collect waste oils in Region 3, while PIP should be used for Regions 1, 2, 4 and 5. Similarly, the same holds for the Waldorf (Southern) and the Columbia (Central) Region locations.

A review of the data presented in Table 12 will reveal that the cost per gallon for waste oil collection and delivery ranges from somewhat over 1¢ to 7¢ per gallon. This indicates the importance of appropriate site location for the reprocessing and central storage facilities, but more importantly, indicates the pressing need for an effective and efficient management system for the collection network. This is apparent from a

Table 12. PARTIAL COLLECTION SYSTEM SUMMARY FOR ALL REGIONS*

Location of Plant	Volume of Pickup	Parameter	Annual Collection Cost	¢/Gal.	Trucks Required		
					Local	Long Haul Trailer	Long Haul Tractor
			$		**	***	***
Baltimore	18×10^6	Good	542,543	3.04	18.43	0.77	0.36
Waldorf	18×10^6	Good	642,280	3.57	18.26	2.25	1.26
Columbia	18×10^6	Good	556,109	3.09	18.34	1.13	0.48
Baltimore	19.8×10^6	Good	593,414	3.00	20.17	.85	.39
Waldorf	19.8×10^6	Good	703,170	3.55	20.00	2.48	1.38
Columbia	19.8×10^6	Good	608,593	3.07	20.08	1.25	0.52
Baltimore	22×10^6	Good	654,221	2.97	22.25	0.95	0.44
Waldorf	22×10^6	Good	775,814	3.52	22.06	2.75	1.53
Columbia	22×10^6	Good	671,219	3.05	22.15	1.39	0.58
Baltimore	19.8×10^6	Worst	1,291,570	6.52	38.54	1.78	0.66
Baltimore	19.8×10^6	Good	593,414	3.00	20.17	.85	.39
Baltimore	19.8×10^6	Best	253,210	1.28	6.76	.45	.25
Waldorf	19.8×10^6	Worst	1,500,529	7.58	38.07	5.18	2.30
Waldorf	19.8×10^6	Good	703,170	3.55	20.00	2.48	1.38
Waldorf	19.8×10^6	Best	333,880	1.67	6.72	1.29	0.87

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* With intermediate storage in all regions except the region in which the central storage facility is located.

** Fractions of trucks indicate that a truck from a neighboring region that is not fully utilized could be called upon to collect in the region of concern.

*** Fractional long-haul trailers indicates a 6,000-gallon trailer is under-utilized or that a tractor can serve several areas.

review of the numerical parameters used for PIP and PUP. The values chosen for overhead, routing factors, the equipment utilization factor, and labor rates significantly affect the overall cost of the system operation. Waiting times for the trucks and drivers, both in the regions and at the plant, and the average speeds attainable by the individual vehicles also significantly affect the costs. It should be noted that leasing was assumed as the most viable alternative for the vehicles. Therefore, the only capital cost incurred for the collection system is the installation of intermediate storage tanks, assuming a central storage facility is available.

It is useful to compare the PIP and PUP output on a region-by-region basis. This has been done and the results are included in Table 12. The results for each region for PUP were compared to three results for each region for PIP. The best (most cost effective) was chosen for each region and the regions were summed for both cost and number of vehicles required to obtain a horizontal entry in Table 12. There are a total of 27 such possibilities. Those presented in Table 12 represent a wide range of unit collection costs, the range of parameters for both the Baltimore and Waldorf locations, and the three plant locations at the three different volumes. It can be seen that the effect of plant location is not as great as the effect of management of the collection system.

The network models presented herein are applicable to any state or any region in the United States. It would only be necessary to re-define the geographic areas and re-state the numerical parameters to apply the system anywhere. As a matter of fact, its full potential would be utilized more effectively in an application of wider geographic scope. Additionally, the distribution network to a very large number of potential customers can be expanded quite readily in a similar fashion as that presented for the PIP and PUP descriptions.

The models can also be used effectively as a management assistance tool in the operation of a collection network by the addition of a real-time segment to handle a dispatching system. In this application, the models will continually update the projected costs, on an hourly basis if necessary, for use as input in the decision-making process.

The numerical results of the PIP and PUP analyses were reviewed and utilized in the cost expansions of the overall system economic model.

The existing 171 collectors that have been identified as operating in the State of Maryland, and perhaps others, could form the basis for a collection system which could be initiated in the very near future.

Pipelining and barging alternatives were compared to the over-the-road costs of the PUP and PIP systems. Pipelining is a substitute for the long-haul tractor-trailer combination of the PIP system. However, at the volumes and distances involved, pipelining is not competitive with over-the-road hauling.

Barging can also be considered as a substitute for the long haul tractor-trailers between the Eastern Shore Region of Maryland and a reprocessing plant located in the Baltimore Harbor area, for example. Barging is economically attractive when compared to over-the-road hauling, if the volumes are commensurate with barge sizes and storage resources.

Optimum barging costs are estimated to be approximately 1/2¢ per gallon, excluding demurrage, compared to 1¢ to 4¢ per gallon for truck hauling. However, standard barge sizes are 840,000 and 1,750,000 gallons. Consequently, approximately one barge-trip per year will satisfy the current and near future waste oil volumes. This situation requires extensive storage facilities on the Eastern Shore or the purchase of a barge with a commensurate increase in storage at the plant to accept this large slug load. Accordingly, the capital investment for either a barge or additional storage facilities is not warranted at this time. If the volume of waste oil from this Region approaches 2,000,000 to 2,500,000 gallons per year, barging should be thoroughly investigated.

SECTION VI

PRELIMINARY DESIGN SUMMARY*

INTRODUCTION

Based primarily on the Waste Oil Recovery Practives State-of-the-Art Report (1972) submitted after the first six months of this project, a detailed preliminary design was developed for a comprehensive waste oil processing facility. This facility is to provide disposal services for all waste oils generated in the State of Maryland. Extensive process literature surveys plus communications with existing re-refiners and equipment suppliers provided the technical base for the actual process design work. The complete Preliminary Design Report from which the summary presented here has been abstracted is presented under separate cover.

In contrast to existing re-refinery operations, the proposed facility is not limited to processing a carefully selected quality of waste oils to produce a lubricating oil which provides the highest value product. The State of Maryland considered the waste oil recovery and reuse program as a mechanism to clean up pollution from this source and to provide a product that could be utilized, if possible, by governmental agencies. Accordingly, all sources of waste oil would be collected and treated or disposed of. In addition, the State of Maryland preferred not to have to market products, which would be the case if non-fuel oil products were considered.

Furthermore, Maryland need not consider the operation of this system to obtain the maximum profit. Unlike private industry, a small profit, a breakeven, or even a loss could be justified on the basis of the overall benefit to the residents, waste oil producing industries, environment, energy needs, resource conservation, pollution control, etc. Though elements of the program could be performed by private industry, the scope and management of the total program were, for this project, deemed best to be under the control of MES.

It is recognized that other overriding conditions could produce other combinations of collection, process, product, and disposal requirements. However, for MES, the following design needs were considered:

1. Treatment or disposal of all types of waste oils that are collected within the State of Maryland.
2. Predominantly, production of fuel oil with some production of lube oil. The products to be used by Maryland State agencies.

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* The Plant design is completely described in a separate report entitled "Preliminary Design Report for a Waste Oil Recovery and Reuse Processing Plant, 1973."

3. The total waste oil recovery and reuse system need not produce a profit.

4. Compliance with all current and projected State and Federal environmental standards.

5. Use of existing state-of-the-art technology.

Since the results of the waste oil surveys (See Section IV) were not available during the early course of the preliminary design work, feedstock waste oil quantities and quality for the processing facility had to be estimated from other sources. Table 13 presents the quantities which were used, as well as analagous quantities from the waste oil survey. These values have been projected to 1975 for design purposes and refer to very broad waste oil categories. Although the gross quantities of oil according to the two sets of data agree very well, this must be fortuitous since the individual quantities vary significantly (especially for the waste industrial oils). As noted on the table, preliminary estimates are that 5 million of the 22 million gallons generated will be non-recoverable, that is, will require incineration or disposal by other than reprocessing. Gross waste oil quantities are not suitable for preliminary design purposes. Therefore, a more detailed breakdown was developed which delineates types and quantities of waste oils. This is presented in Table 14. The term "variable waste oils" refers to those oils which waste oils haulers presently collect on a highly irregular basis. The breakdown into waste crankcase, fuel and industrial oil subcategories is for preliminary design purposes only and was determined based on subjective impressions due to actual haulers. Other waste oil sources were known to exist (due primarily to the state-of-the-art review). Such a category was included for preliminary design purposes at 10 percent of the total quantity of crankcase, industrial, and variable waste oils; again, the subcategorical breakdowns are for preliminary design purposes.

Using the general design criteria and waste oil generation estimates presented above, an actual processing facility was specified and subjected to a preliminary design analysis. The following report subsections outline the rationale for such a facility as well as present summary equipment listings and cost estimates. These data are used in the overall economic analysis of Section VIII of this Report.

PROCESS SELECTION

Plant design and the specification of unit operations depend critically on the expected flow(s) for the process in question and the stipulation to produce, principally, fuel oil. Traditionally, in the petro-chemical-process industries, economic and marketing factors serve to delineate (within relatively narrow boundaries) a "desirable" plant capacity; the plant is then designed using this capacity or throughput as a basis. Unfortunately, such an approach is not directly applicable to the comprehensive re-refining of waste oils on a State-wide basis.

Table 13. WASTE OILS GENERATED IN MARYLAND

	1975 design annual quantity (gal.)	1975 survey projected annual quantity (gal.)
Waste Crankcase Oils	11.1×10^6	9.6×10^6
Waste Industrial Oils	4.9×10^6	6.0×10^6
Other Waste Oils	6.0×10^6	6.6×10^6
TOTAL	22.0×10^6*	22.2×10^6

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* Includes non-recoverable waste oils -------- 5.0×10^6 gal/year.

Table 14. 1975 PROJECTED WASTE OILS

Category	Annual Quantity (gal)	Stream Day Flow * (gal)
Waste Crankcase Oils	11.1×10^6	33,300
Waste Industrial Oils	4.9×10^6	14,700
Variable Waste Oils:**		
Crankcase	1.0×10^6	3,000
Fuel	2.0×10^6	6,000
Industrial	1.0×10^6	3,000
Other Waste Oils:***		
Industrial	1.0×10^6	3,000
Edible	0.5×10^6	1,500
Miscellaneous	0.5×10^6	1,500
TOTAL	22.0×10^6	66,000

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* Based on 330 stream-days per year.

** Total based on private communication with Metropolitan Sewer Cleaning and Pumping Association, Washington, D.C. Breakdown estimate based on possible source information.

*** Estimated at about 10% of the above waste oils in total; breakdown estimate again based on possible source information.

A major portion of the study, which is the subject of this Report, was devoted to characterization of the waste oils generated in the State of Maryland. However, the preliminary design of this section necessarily had to take place in parallel with the waste oil generation studies. Waste oil generation and characterization data was, therefore, assumed for design purposes, and later verified. These estimates related primarily to:

1. The gross amount of waste oil generated annually in the State of Maryland;
2. The general physical-chemical characteristics of waste oils;
3. Expected variations in waste oil as received at the plant or in demand for products due to seasonal or other factors;
4. Processability of the various types of waste oils; and
5. Contaminants in the waste oils as related to process plant pollution control activities.

Some of the points above would be put in much better perspective by actually operating the storage-collection phase of the program, and subsequently, a reduced-scale reprocessing facility. Results inconsistent with the assumptions and estimates used in the preliminary design will be reconsidered in the final design. This will consist of adjusting the design to more realistic flow and processing estimates.

Point #4, above, must be amplified considerably before a final plant design is attempted. The preliminary design as presented involves a number of assumptions relating to waste oil processability. Although the best available data on waste oil re-refining has been used in estimating process and unit operation performance, actual sampling and benchwork characterization, and process testing are required to provide a more secure base for final design. Techniques must also be developed to permit process adjustment on seasonal and year-to-year bases; this is primarily a matter of routine process testing.

Point #5 (pollution control activities) is a matter of availability of technical solutions and legal requirements. Although there is still some doubt, in a technical sense, that unprocessable waste oils and process residues can be disposed in an ultimate, acceptable fashion, the preliminary design presented here considers ultimate waste disposal by isolation, concentration, and reduction of basic wastes to levels suitable for land disposal or recovery of metals by others.

Before the ultimate disposal processes are the subject of final design, two basic actions should take place: 1) further study of ultimate disposal alternatives in terms of both feasibility and potential conformance to pollution control requirements and 2) perhaps more importantly, detailed and exact delineation of the pollution control requirements which will apply to the entire process plant. The latter must be part of the full-scale final design.

The preceding paragraphs do not imply that additional studies on processability and ultimate disposal will lead to as secure design data as that often used in the chemical process industries. Since feedstock characteristics cannot be specified for a comprehensive waste oil disposal facility as they can and are for both chemical process plants and existing waste oil refineries, extensive actual experience provides the only definitive means to determine both the quality and quantity of waste oil in the State of Maryland. Data from actual operations can serve as base for modification of both operations and hardware at an existing waste disposal facility. Of course, similar data will be gathered by instituting a waste oil collection and holding system without an actual processing capability; such an approach will be more realistic than results obtained only through surveys and sampling/ analysis programs.

The existing waste oil re-refining literature, present re-refining practices, and ongoing research and development provided a host of unit processes with potential for the MES waste oil recovery facility. However, many process approaches were considered only briefly because they were speculative and could not be implemented quickly, i.e., on the order of a year. Those processes which were deemed potentially useful are presented in Table 15. The basic function of each process is briefly described and the "product" oil resulting from each is delineated. Note that these unit processes aim at recovery, not ultimate disposal which will be considered later in this section. Unit operations were included in the tabulation based on general applicability to re-refining as well as knowledge of some working experience.

A number of these particular unit processes must be combined into appropriate process trains to yield a technique(s) which will allow the recovery of product from waste oils. Not all the unit processes need be included in a given process plant since some perform similar functions.

Selection of a particular approach must be based on the principle of "best practice" which, in turn, must consider:

1) Necessity -- If there is no viable alternative to a particular unit process, it must be included in a re-refining scheme. Of the unit processes being considered here, only flash distillation and filtration are in essence necessary. Each other can, in principle, be replaced by an alternate unit process.

2) Proven Performance -- Certain of the unit processes have been amply demonstrated in actual re-refining operations, and this was considered to be a positive attribute. Settling, flash distillation, sulfuric acid treatment, solvent extraction, adsorbent

Table 15. POTENTIAL WASTE OIL RE-REFINING UNIT PROCESSES

Unit Process	Function	Product
A. Settling	Removal of gross water, coarse solid solids and other materials heavier than the oil	"Clarified" oil for further processing
B. Centrifugation	Removal of water, solids and other materials heavier than the oil	"Clarified" oil for further processing
C. Flash Distillation	Removal of light ends, naphtha and water	Naphthas and water-free oil product or oil for further processing
D. Chemical Treatment (Caustic Wash, Demulsification, Oxidation and Agglomeration)	Removal of acidic compounds, additives and contaminants stabilized in solution and suspension	Purified oil for further processing
E. Sulfuric Acid Treatment	Removal of additives and contaminants stabilized in solution and suspension	Purified oil for further processing
F. Fractionation	Separation of heavy contaminants plus splitting or oil into various fractions	Various oil cuts for further processing including stabilization
G. Hydrofining	Reduction of nitrogen, sulfur and oxygen contaminants with hydrogen	Purified base lube oil stock
H. Solvent Extraction	Selective extraction of oil and contaminants	Fuel oil stock or refined base lube stock
I. Adsorbent Treatment	Adsorption of metallic sulfuretted, chlorinated and other additives plus odor and color bodies	Purified oil slurried with contaminated adsorbent
J. Filtration	Removes suspended and settleable solids from oil	Oil or base oil stock

treatment, fractionation and filtration possess this attribute in a general sense.

3) Capital Cost -- Low initial investment is desirable for any unit process. For example, settling, stripping, chemical treatment, sulfuric acid treatment, solvent extraction and adsorbent treatment involve lower capital cost than distillation.

4) Operating Costs -- Low operating costs are also to be desired. Settling, flash distillation, chemical treatment, sulfuric acid treatment, fractionation, solvent extraction and adsorbent treatment were compared in this regard.

5) Commercial Availability -- Equipment and techniques should preferably be available commercially (off-the-shelf) in order to facilitate rapid implementation of a waste oil re-refining program. Special fabrication of process equipment can be expensive and time-consuming. Of the unit processes considered, only hydrofining has no commercial source with regard to re-refining waste oils.

6) Process Yield -- Large quantities of wastes or residue from a unit process are undesirable. Only sulfuric acid treatment, filtration and vacuum distillation present significant difficulties in this regard.

7) Product Purity -- Considered in and of itself, a unit process should potentially yield a product which requires little or no further treatment. In a general sense, settling and flash distillation cannot usually meet this criteria, while centrifugation and chemical treatment are somewhat unreliable (i.e., may or may not be adjustable to give a relatively pure product depending on a number of critical variables).

8) Wide Applicability -- Capability of re-refining many types of waste oils is a desirable quality for not only a comprehensive treatment facility but also individual unit processes. Centrifugation, sulfuric acid treatment, vacuum distillation and hydrofining are generally highly specific in their ability to successfully process waste oils and, therefore, are deficient with regard to the criteria of wide application.

9. Energy Requirements -- All other factors being equal, a unit operation should require a low power input. In a general sense, this is nothing more than a requirement for a minimum energy demand by a facility.

Each of the above criteria plus more specific technical considerations were applied to each of the unit operations. A detailed summary of these evaluations is presented as Appendix D of this Report. Ratings of all the unit operations based on the evaluations led to the selection of the following for inclusion in the preliminary design of an MES waste oil processing facility:

1) Chemical Treatment

2) Settling

3) Flash Distillation

4) Adsorbent Treatment

5) Solvent Extraction

6) Filtration

Chemical treatment is presently under development and being used in a limited way; minimal effort should be required, with the assistance of chemical process research laboratories, in providing a treatment scheme(s) with direct application to a range of waste oils. Settling, stripping, and filtration are almost immediately applicable for use on any waste oil since they are state-of-the-art techniques across the existing re-refining industry. Adsorbent treatment is of a similar nature as long as clay is the adsorbent material; due to problems with ultimate disposal and regeneration of spent clay, other adsorbents (e.g., activated carbon) should be looked at carefully before a final design is committed irrevocably to its use. Clay which has been used for polishing an oil and subsequently fired to remove hydrocarbons is, however, generally amenable to successful storage and/or reuse. Of the unit processes selected, solvent extraction is certainly the most speculative. However, solvents like pentane and naphtha are used routinely in waste oil laboratory analyses for insolubles, and propane is being used in full-scale operations. Therefore, at least for the production of fuel oils, solvents are available which can successfully partition contaminants and oils.

ULTIMATE DISPOSAL

Ultimate disposal of process residues and non-recoverable waste oils is an area which has traditionally presented most operational problems in the re-refining industry. Ultimate waste disposal must be as efficient and environmentally sound as operations used in the rest of the processing facility. Table 16 lists the various unit operations and the wastes generated by each. Table 17 lists possible approaches to ultimate waste disposal. Option one is the most comprehensive and would put the most control over the disposal system in the hands of the State. Although capital costs would be much higher than for the other five techniques, this approach would:

1. Minimize the environmental impact of ultimate disposal;
2. Produce concentrated, relatively pure residual wastes which could be disposed of with relative ease;
3. Place ultimate disposal practices primarily under the aegis of the processing facility;
4. Vastly increase the flexibility of the facility for comprehensive waste oil recovery/disposal; and
5. Do away with any possible oil pollution problems due to process residues.

With the above factors in mind as well as the availability of incineration and stack gas scrubbing equipment, total incineration (Option One) was, therefore, selected for preliminary design purposes.

FACILITY DESIGN

The factors (general and technical) just considered lend themselves to overall ratings of unit processes. The pertinent evaluations are presented in Appendix D of this Report. Such evaluations facilitate the selection of particular approaches to be used in a full-scale process plant. The weighting of various factors was subject to judgment but provides a guideline for process selection.

Consideration of the unit processes called out in previous subsections plus their evaluation ratings led to the selection of processes to be included in the MES facility design. These selections are discussed briefly in the paragraphs which follow.

Settling was selected for the WORRP facility based primarily on proven performance, low capital cost, ease of implementation, and wide applicability for waste oils. This unit process would be used as a first treatment step in most re-refining schemes. Its major disadvantage is lack of product purity; that is, in its own right settling does not usually result in a product suitable for use as a fuel oil, let alone a lubricating oil or lube base stock.

Table 16. GENERAL UNIT PROCESS WASTE GENERATION

Unit Process	Waste Generated
1) Settling	BS&W (bottoms, sludge and water)
2) Centrifugation	BS&W
3) Flash Distillation	Petroleum light ends and small amounts of water
4) Chemical Treatment	Process sludge
5) Sulfuric Acid Treatment	Highly acidic and oily process sludge
6) Vacuum Fractionation	Contaminated fractions (usually bottoms or residuum)
7) Hydrofining	Water, hydrogen sulfide, ammonia, metallic sludge and carbon
8) Solvent Extraction	Process sludge
9) Adsorbent Treatment	Small amounts of vapor due to catalytic action
10) Filtration	Waste, contaminated clay, carbon or other solids.

Table 17. ULTIMATE DIPSOSAL PROCESS ALTERNATIVES

No.	Approach	Advantages	Disadvantages
1.	Incinerate waste hydrocarbons, collect heavy metals for recovery and reuse and recover SO_2 and HCl as $CaSO_4$ and $CaCl_2$, respectively.	Storage and transport requirements are minimized. Plant not dependent on external shutdowns. Isolated solid residues are more easily handleable.	Higher capital cost than #3, #5, and #6. Facility would have to meet new, EPA standards for emission.
2.	Store waste materials for eventual disposal when better technology has been developed.	Capital cost lower initially than #1, but increasing with time. No discharges to air or water. Takes advantage of developing technology.	Potential costs. Deferred plant could be much more costly due to inflation. Seismic or meteorological incident could cause spill.
3.	Purchase services of others to dispose of basic process wastes.	Capital cost is transferred to others.	Higher transportation, storage and operating costs than #1, #2, #4, and #6. Liability for improper disposal will transfer to the MES. Loss of thermal value.
4.	Incinerate wastes and dispose of all solids to land.	Storage facilities and transportation less than #3. Plant not dependent on external shutdown.	Toxic materials may contaminate soil and groundwater supplies. Also see #1. Costs for transportation and landfill site.
5.	Dispose of all waste to land.	Lower capital cost than #1, #2, and #4. No airborne contaminant.	Toxic materials may contaminate groundwater and soil. Transportation and landfill site costs. Plant very dependent on external shutdowns.
6.	Dispose of all wastes to land (MES owned & operated)	No airborne contaminants. Capital cost lower than #1, #2, and #4.	See #5. Less dependence on external shutdowns.

Centrifugation has not been included in the facility design due to high capital, operating and maintenance costs as well as lack of proven performance in the waste oil processing field. With settling available as a more straightforward option, it is suggested (even though centrifugation may give somewhat better separation of BS&W from waste oil) that centrifugation not be considered further until more favorable development work or data is forthcoming.

Flash distillation is required for the proposed MES facility as well as almost any other processing scheme. Given existing technology, it provides the most straightforward manner for removing light hydrocarbon contaminants and residual water from waste oil feedstocks. The performance of this unit process has been proven in the existing re-refining industry, and capital and operating costs are reasonable. In general, however, product purity is such that direct use is not recommended and energy requirements can be very significant.

Although existing practice has shown that sulfuric acid treatment of waste oils can lead to excellent product quality, relatively low process yields (especially for fuel oil production which is the main concern here) and almost intractable residue problems lead to a firm recommendation against use of this process in the proposed MES facility.

Chemical treatment is a viable alternative to sulfuric acid treatment for the production of fuel oils. Although demulsifiers, flocculating aids, contaminant oxidizers and conditioning reagents (e.g., caustics) are available commercially, chemical treatment of waste oils has not yet been demonstrated on a large scale. However, low capital and operating costs, high product yields, potential wide application, low energy requirements, and, especially, low residue production make chemical treatment an attractive choice for a waste oil processing facility involved primarily in fuel oil production.

Vacuum distillation is a proven unit process in the waste oil re-refining industry. However, problems with high capital cost, lack of applicability to waste oils over a wide enough range, maintenance, and large amounts of residue or still bottoms weighed against including it in the MES facility design at this time. However, for the production of lubricating oils, vacuum distillation is an extremely promising unit process based on eventually following it with an appropriate finishing process (See the following paragraph). In a comprehensive facility it is necessary to process waste oils containing large amounts of liquid additives (e.g., chlorinated oils or silicones). On these bases, vacuum distillation was not selected for the preliminary design.

Since it aims primarily at finished lube oil production, involves high capital cost and has not been demonstrated in actual re-refining operations, hydrofining was not included in the preliminary design. However, this unit process has great promise and combined with pretreatment such as vacuum distillation should eventually lead to the production of high quality lube base stocks from waste (primarily crankcase) oils. For fuel oil production, however, hydrofining was deemed too advanced a processing technique. Development efforts in the months and years ahead could alter this view significantly.

Like vacuum distillation, solvent extraction has been demonstrated in full-scale operations although not specifically for fuel oil production. Use of pentane, heptane or solvent-grade naphtha rather than propane should be suitable for fuels. Since a comprehensive waste oil processing facility will have to deal with oils containing large quantities of bulk liquid additives, a process like solvent extraction which can partition these additives from the recoverable oil is necessary. Since no other alternative for this operation was available within the existing technology, solvent extraction was selected for preliminary design purposes. Capital and operating costs can be high for solvent extraction relative to a unit process like distillation. Product yield may also be less than that used for preliminary design purposes. Energy requirements for solvent extraction are high relative to flash distillation due to the necessity of solvent recovery. However, without a viable alternative, solvent extraction is included in the preliminary design despite these facts.

Although adsorbent treatment (given that a destructible adsorbent like activated carbon cannot be used) results in a residue production problem, other factors relating to this unit process are favorable enough to weigh in its favor. For instance, the performance of adsorbent (clay) treatment has been widely demonstrated, capital costs are low and implementation should be very straightforward. Furthermore, used adsorbent if incinerated properly presents minimal landfill disposal problems; the oily sludge accompanying the adsorbent is the real pollution problem and, if burned off, leaves no significant contaminants, according to present industrial practice.

Filtration is included in the preliminary design to remove not only spent adsorbent but also flocculated/agglomerated contaminants from the product fuel oil. Rotary vacuum filters have been demonstrated for large-scale, continuous operation in the waste oil processing industry. Although capital cost, operating cost and residue production are high for this unit process, it must necessarily be included in the preliminary design, given the solids which must be removed to yield an acceptable product oil.

Each unit process removes contaminants which are, basically:

1. Gross water, coarse solids and other materials heavier than oil, i.e., BS&W or setteable materials (by settling);

2. Light ends, naphtha and water, i.e., relatively volatile materials (by flash distillation);

3. Acidic compounds, additives and contaminants stabilized in solution and suspension, including nitrogen, sulfur, oxygen, and metal containing organic compounds (by adsorbent treatment and solvent extraction);

4. Odor and color bodies (by adsorbent treatment); and

5. Suspended and colloidal solids (by filtration).

The proposed waste oil re-refining process involves two basic process trains:

1. Adsorption treatment - chemical treatment-settling-flash distillation-adsorbent treatment-filtration.

2. Solvent treatment - chemical treatment-settling-flash distillation-solvent extraction.

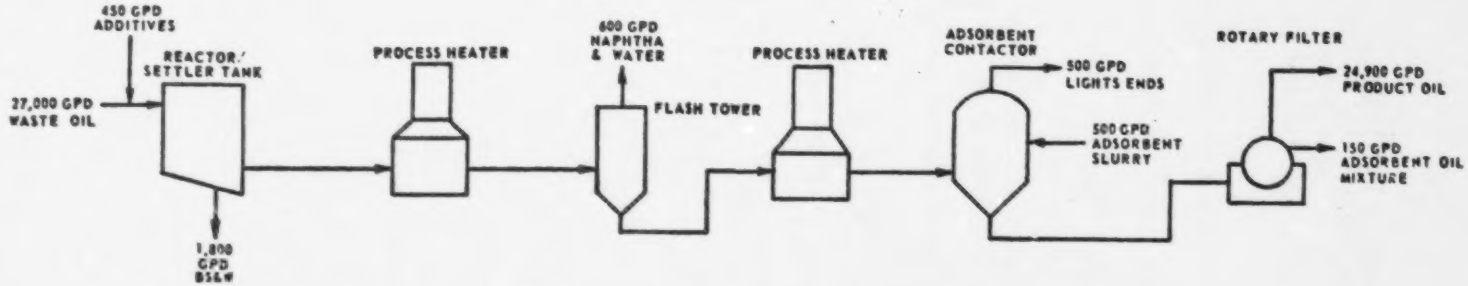
The first of these serves as a fairly standard waste oil treatment procedure. Primarily, it can treat waste crankcase and industrial oils which contain the usual contaminants handled in the re-refining industry but not waste oils composed of large amounts of bulk liquid additives. The solvent extraction train is meant to handle oils "contaminated" in the latter fashion. That is, light hydrocarbon solvent(s) serves to partition liquid additives from the recoverable oil.

These two trains can be termed adsorbent treatment and solvent treatment respectively. Distinctive elements of each may be included in the other to enhance results in a practical situation; this is a requirement for nothing more or less than process plant flexibility.

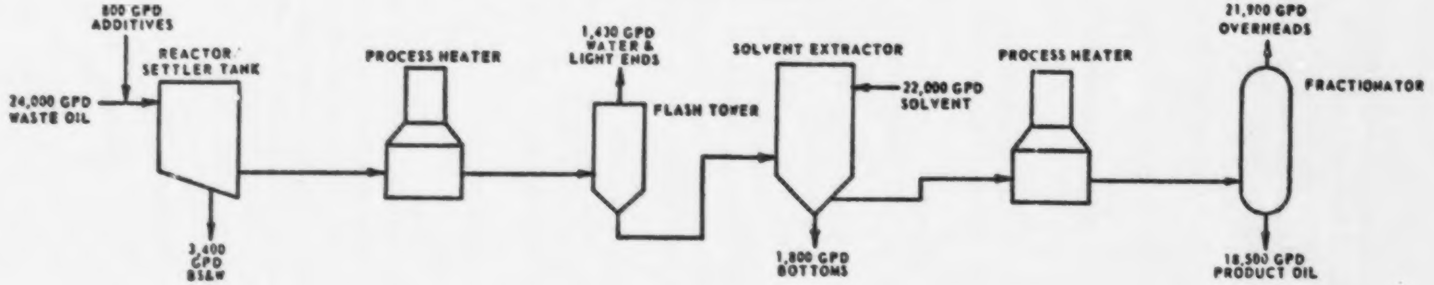
Figure 3 illustrates these two basic process trains and represents a simplified version of the process flowsheet which is presented in the Preliminary Design Report. In terms of the processing estimates which are presented below, these two main subsections can be considered to provide a) standard, b) adjusted, or c) special processing. Standard processing refers basically to adsorbent treatment. Adjusted processing refers basically to adsorbent treatment with either treatment conditions or reagents adjusted beyond what is necessary for the common waste crankcase oils; adsorbent treatment preceded by a rough solvent extraction could also be included in this processing category. Special processing

Figure 3. ADSORBENT AND SOLVENT TREATMENT SUBSECTION SCHEMATICS

ADSORBENT TREATMENT SUBSECTION


450 GPD ADDITIVES
27,000 GPD WASTE OIL
REACTOR/ SETTLER TANK
1,800 GPD BS&W
PROCESS HEATER
600 GPD NAPHTHA & WATER
FLASH TOWER
PROCESS HEATER
ADSORBENT CONTACTOR
500 GPD LIGHTS ENDS
500 GPD ADSORBENT SLURRY
ROTARY FILTER
24,900 GPD PRODUCT OIL
150 GPD ADSORBENT OIL MIXTURE

SOLVENT TREATMENT SUBSECTION


800 GPD ADDITIVES
24,000 GPD WASTE OIL
REACTOR/ SETTLER TANK
3,400 GPD BS&W
PROCESS HEATER
1,430 GPD WATER & LIGHT ENDS
FLASH TOWER
SOLVENT EXTRACTOR
22,000 GPD SOLVENT
1,800 GPD BOTTOMS
PROCESS HEATER
21,900 GPD OVERHEADS
FRACTIONATOR
18,500 GPD PRODUCT OIL

refers to the basic solvent extraction treatment train. Other variations (based on variation of individual unit operations) are possible but the above suffices for preliminary design purposes.

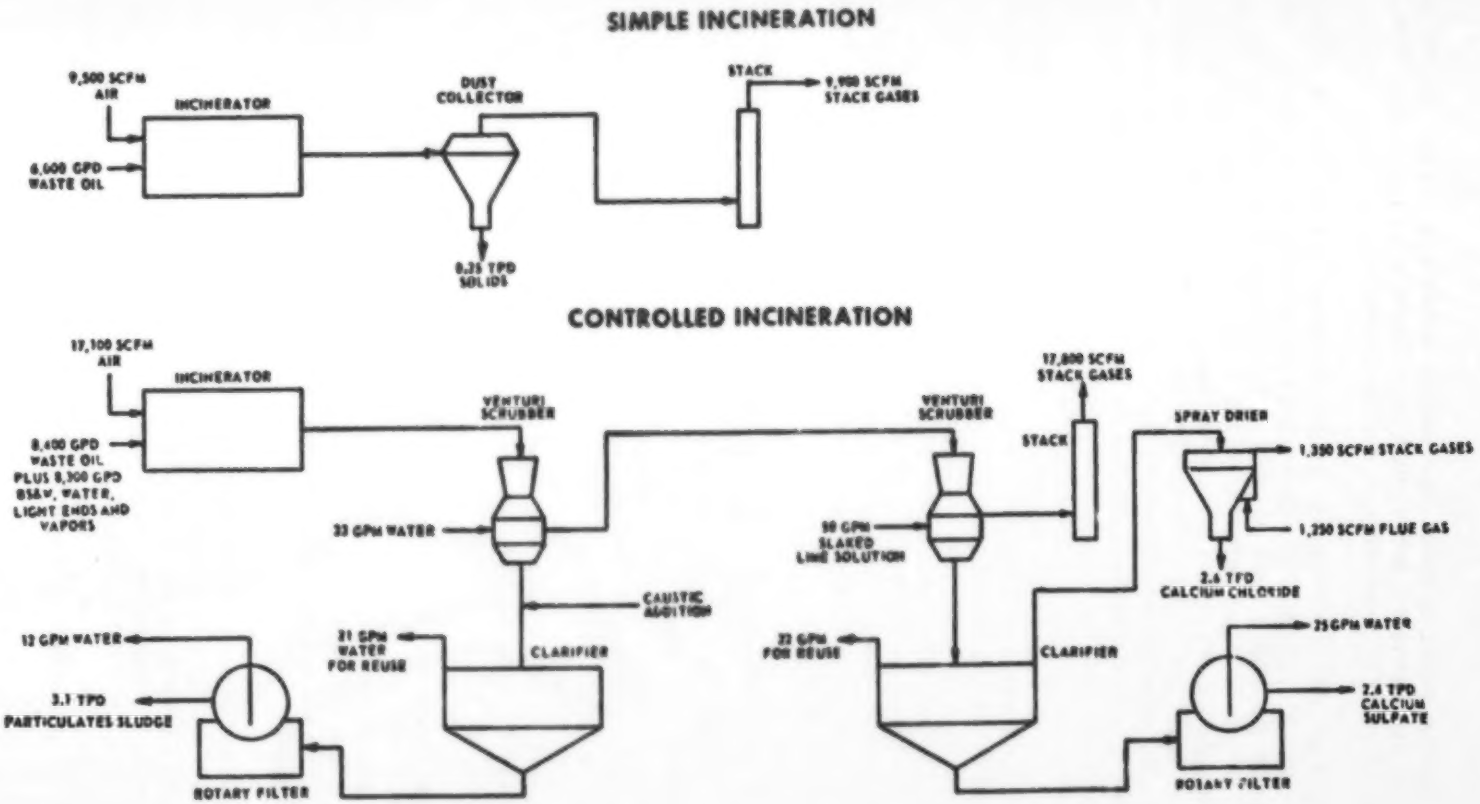
The adsorbent treatment train involves reagent addition to a feed waste oil stream of 27,000 GPD. Approximately 450 GPD of reagents, including caustic conditioner, demulsifiers, and flocculants, are added. A heated (200°F) process tank (reactor/settler) serves both as a mixing and a settling vessel for the conditioned waste oil; 1,800 GPD of BS&W results from the settling process and subsequently must be incinerated. The oil from reaction/settling is heated (450°F) and sent to a tower where naphtha and water still contaminating the oil are flash distilled and, subsequently, either incinerated or used profitably (possibly the case for the naphtha). The oil from the flash tower is then heated further (550°F) and pumped to an adsorbent contactor where it is mixed with 500 GPD of adsorbent and carrier oil slurry; in the case of clay adsorbent, this slurry volume contains about 3.6 TPD of clay. The adsorbent serves to remove acidic compounds, additives, and contaminants in small quantities as well as some odor and color bodies. After adsorbent treatment the oil is filtered yielding 24,900 GPD of product oil and about 150 GPD of oily adsorbent cake. Filtration serves to remove not only the adsorbent but also the flocculated, relatively neutral-density solids formed in the reactor settler.

The solvent treatment subsection involves the same type processing as for adsorbent treatment up to the point where solvent extraction takes place. First, 800 GPD additive reagents are mixed with 24,000 GPD of feed waste oil. Reaction settling then results in 3,400 GPD of BS&W. Flash distillation follows, yielding 1,400 GPD of water and light ends (or naphtha). Solvent extraction (at about 110°F) follows that and results in 1,800 GPD of process sludge or bottoms which must be stripped first of residual solvent and then disposed of by incineration. The oil/solvent mixture from the extractor is then subjected to a simple fractionation process to recover 21,900 GPD of solvent overheads and about 18,500 GPD of product oil.

The schematics for the two subsections represent simplifications of the flowsheet for the complete process plant. The flow values are approximate and include adjustment for relatively minor factors like vapor losses and adsorbent carrier oil. For a complete materials work-up and detailed flowsheet the Preliminary Design Report for the Project should be consulted.

The previous report subsection outlined the selection of complete incineration for non-recoverable waste oils and process residues. The flowsheet, Figure 4, illustrates this plant subsection. The basis for the simple incineration subsection design was 6,000 GPD of waste oil requiring only dust collection on the exit gases to assure that no visible emission occurs. The controlled incineration subsection is based on 8,400 GPD of waste oil burned directly plus 8,300 GPD of BS&W, water,

Figure 4. INCINERATION SUBSECTION SCHEMATIC



SIMPLE INCINERATION

CONTROLLED INCINERATION

9,500 SCFM AIR
6,600 GPD WASTE OIL
INCINERATOR
DUST COLLECTOR
0.25 TPD SOLIDS
STACK
9,900 SCFM STACK GASES
17,100 SCFM AIR
8,400 GPD WASTE OIL PLUS 8,300 GPD BS&W, WATER, LIGHT ENDS AND VAPORS
INCINERATOR
VENTURI SCRUBBER
33 GPM WATER
CAUSTIC ADDITION
CLARIFIER
21 GPM WATER FOR REUSE
12 GPM WATER
3.1 TPD PARTICULATES SLUDGE
ROTARY FILTER
VENTURI SCRUBBER
50 GPM SLAKED LIME SOLUTION
STACK
17,800 SCFM STACK GASES
22 GPM FOR REUSE
CLARIFIER
SPRAY DRIER
1,350 SCFM STACK GASES
1,250 SCFM FLUE GAS
2.6 TPD CALCIUM CHLORIDE
25 GPM WATER
2.4 TPD CALCIUM SULFATE
ROTARY FILTER

light ends and vapors from the processing subsections; this total 16,700 GPD of wastes can be highly contaminated and, therefore, must be subject to strict pollution control during processing as is discussed briefly in the following paragraph. Note that the BS&W, water, etc. indicated in Figure 3 total to 150 GPD more than that fed to controlled incineration; this difference is accounted for by naphtha which is used as process fuel or sold as pruduct. Complete material balances are not presented for the incineration subsections since they should be developed during the final design in conjunction with equipment suppliers.

Simple incineration applies to oils or residues which are not contaminated with heavy metals, fine particulates, sulfur or halides but yet cannot be turned reasonably into a valuable product; such material can be burned directly with only simple dust collection from the stack gases. Some waste edible oils as well as materials like fuel oil tank slops would be amenable to such treatment. Contaminated oils and residues will have to be burned under closely controlled conditions. Heavy metal particulates, sulfur dioxide, and halides (primarily chloride) will have to be scrubbed from the controlled incinerator's stack gases and recovered as a particulate sludge, calcium sulfate, and calcium chloride, respectively. These materials can be disposed of to the heavy metals industry, landfill and chemical industry, used for snow melting, disposed of on land, etc.

Table 18 gives estimates of stream-day flows for feed waste oils based on the processing categories discussed above. "Other Disposal" primarily refers to sale of special waste oils (e.g., oil-based paint pigment or insecticide) to other parties. Whereas Table 13 presented quantities of waste oil entirely in terms of source category, Table 17 lists them by processing categories; the latter is necessary as a feedstock base for calculations in preliminary design. Note also that plant operation is expected to involve approximately 330 stream-days per year of operation at 24 hours per day. Thus an effective (complete facility) down time of 35 days has been alloted for major repairs and maintenance.

FACILITY TANK FARM

The preliminary design of the MES waste oil processing facility includes considerable attention to oil storage. Receiving tanks and product oil storage tanks were included in the design considerations. The Preliminary Design Report contains detailed justification for such tankage. The following paragraphs outline briefly the rationales for tankage as well as the gross results from the design effort.

Receiving facilities must consider the regularity with which oils can be delivered to the plant, daily (statistical) variations in quantities received as well as seasonal variations. Estimates of these factors led to 4 main receiving tanks at 70,000 total gallons to receive 66,000 gallons of waste oil per day. Similar considerations led to a

Table 18. ESTIMATED STREAM-DAY FEED FLOWS (1975)

Category	Stream-Day Flow (gal)
Waste Crankcase Oil:	
Standard Processing	16,200
Adjusted Processing	9,800
Special Processing	5,000
Simple Incineration	2,100
Controlled Incineration	3,200
TOTAL	36,300
Waste Industrial Oil:	
Standard Processing	10,700
Adjusted Processing	3,100
Special Processing	2,400
Simple Incineration	1,800
Controlled Incineration	2,400
Other Disposal	300
TOTAL	20,700
Waste Fuel Oil:	
Adjusted Processing	1,800
Special Processing	1,200
Simple Incineration	1,200
Controlled Incineration	1,800
TOTAL	6,000
Waste Edible & Miscellaneous Oils:	
Special Processing	800
Simple Incineration	900
Controlled Incineration	1,000
Other Disposal	300
TOTAL	3,000

specification for 23 primary waste oil feedstock tanks of 1,185,000 gallons. Since reaction/settling in the process plant is a batchwise operation, 4 tanks of 145,000 total gallons are also required to hold the effluent from the reactor/settlers. Note that the above number and volume of tanks are in line with existing re-refining practice.

Product tank requirements are set mainly by product demand schedules. Since the proposed facility was designed to be used primarily for fuel oil production, seasonal demand for fuel oil should determine the necessary extent of product storage facilities. Although the State of Maryland may be the sole buyer for the plant's product, fuel oil demand in the Baltimore-Washington area provided a reasonable base for preliminary design estimates. Ten product tanks were deemed necessary at 9,850,000 gallons based entirely on an analysis of fuel oil demand. Three of these tanks are for product cutter stock used in blending to meet specifications.

LAND REQUIREMENTS

Land for the proposed waste oil processing facility must be allocated to the basic tank farm (storage and holding), receiving tankage, the two treatment subsections, the incineration system, plant buildings and parking, and road and rail access.

Table 19 lists the preliminary land estimates for these elements. Note that the various tankage requirements account for about one-third of the land area. For preliminary purposes, about 5/8 acre has been included for possible future expansion, outdoor storage and contingency. Space has also been allotted for boundary clearance with adjoining property; this is critical for tanks holding flammable liquids and for process equipment which presents a potential fire hazard. In-plant clearance between subsections and installations is also necessary. American Petroleum Institute Standards for oil storage tanks cover such considerations in detail and should be used for final design.

Table 19. LAND REQUIREMENTS

Plant Element	Area (acres)
Tank Farm	3.7
Receiving Tankage	0.2
Adsorbent Treatment Subsection	0.7
Solvent Treatment Subsection	0.8
Incineration Subsection	0.8
Plant Buildings and Parking	0.5
Road and Rail Access	1.2
Expansion and Outdoor Storage	0.6
Subsection and Plant Clearance	4.5
TOTAL ----------	13.0

The above considerations may eventually prove crucial due to high land costs. Since land involves more general economic and political considerations, its cost has not been included in the capital cost estimates developed here.

COST ESTIMATES

Table 21 is an estimate of the capital cost for the entire processing section of the proposed facility. This capital cost is used as an input to Section VIII on program economics.

Table 20 contains a tabulated summary of preliminary cost estimates for the process equipment discussed in the previous sections. These estimates are arranged in four groups corresponding to the four major processing subsections. It should be noted that the incineration subsection requires a large portion of the total capital cost which could even be larger if more sophisticated air pollution control systems eventually prove necessary (e.g., a baghouse as opposed to a venturi scrubber for particulates removal). The other major subsection in terms of cost is represented by the reactor/settler tanks; final design should devote considerable effort to reduce its cost. For instance, if standard carbon steel tankage could be used for this purpose as opposed to agitated, heater reactors, a major cost savings would be achieved. The adsorption treatment and solvent extraction subsections are nominal in terms of relative cost and, therefore, probably cannot be the object of major cost savings efforts (Additional details are included in Appendix D).

A summary of tank cost for a full-scale tank farm is shown in Tables 22 and 23. These costs relate directly to the discussion of the facility tank farm and, again, are detailed in entirety in the Preliminary Design Report.

Tables 24 and 25 are summaries of preliminary capital cost estimates for the small or first-stage base plant. This facility has a processing capacity of 22,000 GPD of waste oil plus an additional 8,400 GPD incineration capacity. That is, the incinerator subsections are the same as for the full-scale plant while the other equipment has been selected from that of the full-scale facility so as to provide a representative processing capability. This plant, therefore, can serve as a first-stage facility in the eventual development of a full-scale, comprehensive process plant and program.

PRELIMINARY DESIGN PRODUCT FLOWS

Table 26 lists the preliminary estimates of produce flows based on both the type of waste oil and the processing approach. The product flows of Table 26 have been adjusted to account for product oil which 1) added

Table 20. PRELIMINARY CAPITAL COST ESTIMATE FOR A FULL-SCALE MES WASTE OIL RECOVERY PLANT*

Basic Equipment Costs	$1,110,000**
Field Materials (75%)ⓐ	820,000
Direct Material	$1,930,000
Direct Field Labor (35%)	650,000
Direct Costs	$2,580,000
Indirect Costs (43%)ⓑ	1,110,000
Bare Module Costⓒ	$3,690,000
Plant Buildingsⓓ	170,000
Base Plant Cost	$3,860,000
Site Developmentⓔ	190,000
Estimated Total Plant Cost	$4,050,000
Estimated Working Capital	$ 160,000

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* Total costs estimated according to "Rapid Calculation Charts", Chemical Engineering, Jan. 13, 1969 for carbon steel. Does not include land costs. Costs have been escalated to first quarter 1973.

** Includes $25,000 for pumps.

ⓐ Secondary cost element including piping, instrumentation, foundations and other concrete work, local steel, electrical and other utilities, paint, etc.

ⓑ Secondary cost element including construction overhead (field supervision, temporary field facilities, small tools, etc.) and engineering and contractor fee (direct engineering labor, overhead office costs, etc.) and interest during construction, owners' costs & 1 month's startup.

ⓒ This cost does not include site development, pilings, buildings major storage or other offsite facilities. Offsite costs associated with the complete WORRP system are considered elsewhere in this report (e.g., Section).

ⓓ Laboratory, office, warehouse and shop space, fully equipped.

ⓔ Estimated at 5 percent for this process plant module.

Table 21. PROCESS EQUIPMENT COSTS BY PLANT SUBSECTION

ITEM		PURCHASED COST
Reactor/Settler Tank Subsection:		
Standard Processing-Crankcase Oils	2 at 30,000 gal.	$ 96,800
Standard Processing-Industrial Oils	2 at 20,000 gal.	73,600
Adjusted Processing	2 at 45,000 gal.	132,200
Special Processing	2 at 30,000 gal.	96,800
Caustic Reagent Tank	2,500 gal.	2,100
Misc. Reagent Tanks	5 at 275 gal.	3,200
Oxidizer Reagent Tank	1,000 gal.	1,600
	SUBTOTAL	$406,300
Adsorbent Treatment Subsection:		
Heat Exchanger	350 ft^2	$ 3,900
Process Heater	1.5 x 10^6 Btu/hr.	15,400
Flash Tower	18 x 4 ft.	3,100
Air Cooler	15 ft^2	2,300
Process Heater	5.7 x 10^6 Btu/hr.	25,500
Absorbent Contactor	28 x 6 ft.	6,600
Air Cooler	15 ft^2	2,300
Adsorbent Addition Tank	30 gal.	2,500
Adsorbent Feed System	550 lbs/hr	4,000
Air Cooler	210 ft^2	4,100
Rotary Precoat Filters	12 x 8 ft.	67,800
Air Cooler	210 ft^2	4,100
Naphtha Holding Tanks	10,000 & 20,000 gal	9,100
	SUBTOTAL	$150,700

Table 21 (Continued). PROCESS EQUIPMENT COSTS BY PLANT SUBSECTION

ITEM		PURCHASED COST
Solvent Treatment Subsection:		
Heat Exchanger	290 ft^2	$ 3,500
Process Heater	2.7x10^6 Btu/hr	17,900
Flash Tower	22x4 ft	3,700
Air Cooler	15 ft^2	2,300
Air Cooler	170 ft^2	3,400
Agitated Tank Reactors	2 @ 7,100 gal	66,200
Solvent Tank	22,000 gal	9,800
Bottoms Tank	9,500 gal	6,500
Extract Tank	15,500 gal	7,000
Process Heater	4.7x10^6 Btu/hr	22,600
Fractionating Column	20x2.5 ft	3,900
Air Cooler	535 ft^2	7,600
Air Coolers	3 @ 15 ft^2	6,900
	Subtotal	$161,300
Incineration Subsection:		
Belt Conveyors	3.9 TPD	$ 2,400
Multiple Hearth Kiln	750 lbs/hr	45,000
Routine Incinerator	9x10^8 Btu/day	73,500
Controlled Incinerator	16x10^8 Btu/day	70,000
Particulates Scrubber	17,100 SCFM	52,500
Acid Gas Scrubber	17,100 SCFM	45,000
Particulates Clarifier	33 gpm	7,900
Acid Salts Clarifier	51 gpm	7,900
Rotary Filter	100 ft^2	34,000
Particulate Slurry Tank	39,000 gal	7,900
Gypsum Slurry Tank	22,000 gal	4,600
Slaker and Feed Hopper	9 TPD	12,200
	Subtotal	$362,900
	TOTAL	$1,080,000

Table 22. PRELIMINARY CAPITAL COST ESTIMATE FOR A FULL-SCALE MES TANK FARM

Direct Costs	$1,090,000*
Indirect Costsⓐ	270,000
Base Tank Farm Cost	$1,360,000
Site Developmentⓑ	140,000
Bare Tank Farm Cost	$1,500,000
Contingencyⓒ	150,000
TOTAL ⓓ	$1,650,000

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* Includes 10% for tank foundations and $41,000 for pums.

ⓐ Estimated at 25% for engineering labor, overhead, office costs, field supervision, etc.

ⓑ Estimated at 10% for preliminary purposes.

ⓒ Contingency is 10% based on 5% for site development, indirect costs and foundation estimates accuracy plus 5% for inaccuracies in basic equipment estimates.

ⓓ Does not include land costs, working capital, start-up costs, owner's expenses (borrowed capital interest, legal expenses, management expenses, etc.).

Table 23. SUMMARY OF MES WASTE OIL PROCESSING FACILITY TANK REQUIREMENTS

Tank Type	No.	Total Volume (gal)	Installed Cost
Receiving	4	70,000	$ 48,000
Feedstock			
Crankcase Standard Processing	2	350,000	52,000
Industrial Standard Processing	2	120,000	33,000
Adjusted Processing	5	175,000	58,900
Special Processing	4	150,000	49,000
Other Waste Oils	6	205,000	78,200
Simple Incineration	1	75,000	19,200
Controlled Incineration	3	110,000	35,000
Process Holding	4	145,000	48,700
Product			
Lube Oil Base Stock	3	200,000	50,500
Cutter Stock	3	900,000	92,700
Blended Fuel Oil	4	8,750,000	389,600
TOTALS	41	11,250,000	$955,000

Table 24. PRELIMINARY CAPITAL COST ESTIMATE FOR A FIRST-STAGE MES WASTE OIL RECOVERY PLANT*

Basic Equipment Costs	$ 570,000
Field Materials (75%)[a]	428,000
Direct Material	$ 998,000
Direct Field Labor (35%)	349,000
Direct Costs	$1,347,000
Indirect Costs (43%)[b]	580,000
Bare Module Cost[c]	$1,927,000
Plant Buildings[d]	170,000
Base Plant Cost	$2,097,000
Site Development[e]	105,000
Estimated Total Plant Cost	$2,200,000
Estimated Working Capital	$ 125,000

* Total costs estimated according to "Rapid Calculation Charts", Chemical Engineering, Jan. 13, 1969 for carbon steel. Does not include land costs. Costs have been escalated to the first quarter, 1973.

[a] Secondary cost element including piping, instrumentation, foundations, and other concrete work, local steel, electrical and other utilities, paint, etc.

[b] Secondary cost element including construction overhead (field supervision, temporary field facilities, small tools, etc.) and engineering and contractor fee (direct engineering labor, overhead office costs, etc.) and interest during construction, owner's costs & 1 month's start-up.

[c] This cost does not include site development, pilings, buildings, major storage or other off-site facilities. Off-site costs associated with the complete WORRP are considered elsewhere.

[d] Laboratory, office, warehouse and shop space, fully equipped.

[e] Estimated at 5% for this process plant module.

Table 25. PRELIMINARY CAPITAL COST ESTIMATE FOR A FIRST-STAGE MES TANK FARM

Direct Costs	$ 565,000
Indirect Costs ⓐ	141,000
Base Tank Farm Cost	$ 706,000
Site Development ⓑ	71,000
Bare Tank Farm Cost	$ 777,000
Contingency ⓒ	78,000
TOTAL ⓓ	$ 860,000

ⓐ Estimated at 25% for engineering labor, overhead, office costs, field supervision, etc.

ⓑ Estimated at 10% for preliminary purposes.

ⓒ Contingency is 10% based on 5% for site development, indirect costs and foundation estimates accuracy plus 5% for inaccuracies in basic equipment estimates.

ⓓ Does not include land costs, working capital, startup costs, owner's expenses (borrowed capital interest, legal expenses, management expenses, etc.)

Table 26. ESTIMATED STREAM-DAY PRODUCT FLOWS (1975)

Category	Stream-Day Flow (gal)	Yield (%)
Waste Crankcase Oil:		
Standard Processing	13,800	85
Adjusted Processing	7,000	71
Special Processing	3,800	76
TOTALS	24,600	68
Waste Industrial Oil:		
Standard Processing	9,300	87
Adjusted Processing	2,200	71
Special Processing	1,800	76
TOTALS	13,300	64
Waste Fuel Oil:		
Adjusted Processing	1,300	71
Special Processing	900	76
TOTALS	2,200	37
Waste Edible & Miscellaneous Oils:		
Special Processing	600	76
TOTALS	600	20
GRAND TOTALS	40,700	62

*Based on percent of the feed stream to a particular processing subsection which the product represents.

to process streams as a carrier fluid for reagents and adsorbent and 2) used as in-plant process fuel.

As mentioned previously, basic products which will be produced by the plant include fuels, lubricants and solvents (naphtha/light ends). The fuels are primarily heating grade oils — #4 and #5. Number 6 heating oil may be produced in small quantities depending on the viscosity of the waste oil feedstocks. Additionally, approximately 1,500 GPD of lubricants (including hydraulic oils and motor oils) could be produced in small quantities by processing of waste crankcase oils. For preliminary purposes, only 500,000 gallons per year should be allocated to lube oil products; larger amounts of lube oil production would be more than Maryland State Agencies could reasonably accommodate. Small amounts of solvents also will be produced as a byproduct. Essentially, these originate from gasoline dilution of crankcase oil, solvent contamination of industrial oils, and the effects of adsorbent treatment on waste oils.

SECTION VII

COSTS OF SYSTEM ALTERNATIVES

INTRODUCTION

The mathematical techniques presented in Appendix K (the Cash Flow, Revenue, and Profit Model) and the values for the parameters shown in the tables of Appendix L were utilized to generate the costs, revenues received, cash flow, and cost per gallon of product for twenty alternative plant and operating conditions. These include:

1. Two different types of plant -- mechanical-chemical and vacuum distillation;
2. Two methods of financing -- total amortization and equity financing;
3. Three modes of payment for the waste oils collected and delivered to the plant --
   - a) The source or collector is paid 2¢ per gallon,
   - b) The source or collector is paid 2¢ per gallon, but the program is supported by a 2¢ per gallon subsidy, or
   - c) The source or collector is paid 2¢ per gallon, but the program is supported by a 4¢ per gallon subsidy.
4. Two values for volume of feed stock processed -- 20 million gallons per year (nominal) and 30 million gallons per year.

The values for net income before taxes resulting from implementation of these twenty alternatives are summarized on Table 27 on page 76.

The chemical-mechanical plant in the preliminary design was considered in two size ranges: 1) 18,000,000 gpy, 19,800,000 gpy, and 22,000,000 gpy, clustered around a nominal 20 million gpy capacity, and 2) 30,000-000 gpy throughout, all based upon 330 days' operation per year.

On the basis of data and information generated during the course of another program being sponsored by the EPA (National Oil Recovery Corporation [NORCO], Bayonne, New Jersey and NORCO Private Communication), cost estimates were provided which enabled an additional comparison of the mechanical-chemical plant with a vacuum distillation plant followed by hydrofining of the refined products. The capacity of this plant is 30,000,000 gpy. In addition, this plant could produce both lube stock and fuel oil.

As the plants could be financed by either the State or private industry at variable rates, two financing alternatives were considered: 100 percent financing at 7.25 percent and 100 percent capitalization, requiring zero financing. This comparison gives information on the effect of interest rate on the unit cost of the product.

The price of the waste oil feed to the plant is important in evaluating overall plant economics. To determine the impact on the profit picture, the cost of the waste oil and feed, and a potential subsidy by the State, a broad range of values were compared. To reflect having to pay the collectors 2¢ per gallon to encourage the delivery of all waste to the plant, a value of -\$0.02 per gallon was utilized in the model for q_1 (the fee for waste oil picked up).

In order to assess the impact of support for the program, subsidies of 2¢ and 4¢ per gallon were used. These are equivalent to q_1=0.0, and +\$0.02, respectively.

In addition to the above parameters, the value of the resultant products was increased. Projections for fuel and lube costs in 1975 and 1977 indicate a possibility for increased prices because of trends in petroleum product shortages. As a plant could not be constructed and operated until about that time, it seems reasonable to utilize product values that reflect respective market conditions. Accordingly, product values for lube and fuel stocks were increased approximately 25 percent to 25¢ per gallon and 15¢ per gallon, respectively.

Accordingly, the following "Cases" were considered:

CASE I -- MECHANICAL-CHEMICAL PLANT

This is the type plant for which a preliminary design was prepared (See Section VI). It has a capacity of 19.8 million gallons per year, and includes 11,250,000 gallons of storage for both feed and product as well as two incinerators: one for relatively easily disposable materials and another for more hazardous or difficult to dispose of materials. The analysis for this Case considered 100 percent financing at an interest rate of 7.25 percent per annum.

CASE II -- MECHANICAL-CHEMICAL PLANT

In this particular Case, the Mechanical-Chemical Plant of Case I was utilized with the exception that more favorable conditions were assumed for this plant than in Case I. For instance, the quantity of waste oil processed was raised to 22,000,000 gallons per year. A favorable contingency factor was used to effect the possibility of lower construction costs. Land costs were one-tenth those of Case I, assuming that State land was already available. Plant life was extended to 15 and 25 years for the processing plant and tank farms, respectively, plus other benefits such as lower interest rates and personnel costs.

Comparisons of Case II and Case III conditions indicate the need to consider every advantage possible for more effective and less costly operation of the plant. This operating program results in a significant net profit before taxes.

CASE III -- MECHANICAL-CHEMICAL PLANT

Case III is the contrary of Case II, i.e., more pessimistic assumptions were made that would severely penalize the operation of the facility from a cost and revenue point of view, in order to indicate the vulnerability of the program to sustain large losses if several of the significant variables are adversely affected by mismanagement. The quantity of waste oil processed is 18,000,000 gpy. These constraints result in substantial financial loss.

CASE IV -- MECHANICAL-CHEMICAL PLANT

To determine the impact of financing on the cost per gallon of product produced, Case I was re-run with 100 percent equity capital, i.e., zero financing costs for plant construction capital needs. The subsidies in this case result in a favorable net profit before taxes.

CASE V -- MECHANICAL-CHEMICAL PLANT

Recent unpublished research results indicate the potential for sale of process bottoms for a value approximately equivalent to costs for hauling to a disposal site. Full-scale application of such research results would have the effect of eliminating significant load to the proposed plant incinerators and could permit elimination of one of the two incinerators. Accordingly, Case I was run with only one incinerator. The effect of this modification is only moderate compared to the losses sustained in Case I.

CASE VI -- VACUUM DISTILLATION-HYDROFINING

Information was made available to this program through the Environmental Protection Agency describing a concept utilizing vacuum distillation followed by hydrofining for product polishing. Information was available related to cost and revenue data for a 29,000,000 gallon per year capacity plant. The concept was "normalized" to 30,000,000 gallons per year in order to permit analysis under the same conditions as in Cases VII and VIII, and provision was made for additional storage tanks and an incinerator. The additional waste oil over that projected to be available within the State of Maryland (8 million gpy) was assumed to be available from neighboring states, and the out-of-state supply was assumed to consist of only recoverable oils. Non-recoverable oils were to remain within the source states for ultimate disposal.

Since the State of Maryland currently has a need for fuel oil, the analysis assumed that the plant was constrained to produce half fuel oil and half lube oil stock. Also, the plant was assumed to be installed and operated by private investors, but with 100 percent financing. Accordingly, various State and local taxes were ascribed to the operating costs.

CASE VII -- EXPANDED MECHANICAL-CHEMICAL PLANT

The concept of mechanical-chemical unit processes for waste oil recovery results in high flexibility for accommodating a wide variability in quality of feedstock, and producing a wide variety of products. Such a plant would utilize a proportionately larger number of personnel and result in higher operating costs than other systems. However, for the sizes of plant considered and with full use of automation, the plant capacity could be significantly increased without adding any additional personnel.

Accordingly, the plant capacity was increased to 30 million gpy with associated increased capital costs and variable operating expenses, but the number of plant personnel was kept constant. As in Case VI, it was stipulated that such a plant would be installed with private capital, would be taxed, and the 80,000,000 additional gallons of feedstock were assumed to consist of recoverable waste oils only. Only the subsidized alternative at 4¢ per gallon shows a favorable profit picture.

CASE VIII -- EXPANDED MECHANICAL-CHEMICAL PLANT - 25% INCREASE IN PRODUCT VALUE

Case VII was re-run with the value of fuel oil and lube oil stock products increased to 15¢ per gallon and 25¢ per gallon, respectively. In addition, the value of cutter stock was increased to 15¢ to reflect increased costs for this item. The subsidized alternatives show a favorable profit picture. For Cases VI, VII, and VIII, the program could break even or make a small profit, for all Alternatives "a", "b", and "c", if collection costs could be decreased.

SUMMARY OF PLANT ALTERNATIVES

From the various computer runs, it was possible to evaluate the impact on cost per gallon of product produced due to:

1. Size of Plant,
2. Initial Cost of Plant,
3. Rate of Interest on Capital Investment,
4. Size of Subsidy,
5. Bottoms Incineration Capability,
6. Depreciation,
7. Quality of Source Material,
8. Price of Product, and
9. Type of Product.

1. Size of Plant

The economics associated with the increased size of the mechanical-chemical plant are apparent. The nominal 20,000,000-gallon-per-year Base Plant resulted in an average breakeven sales price for fuel oil of

Table 27. SUMMARY OF CASHFLOW REVENUE AND PROFIT ANALYSES

TWENTY ALTERNATIVE SYSTEM CAPACITIES

Alternative 1/		Volume Gal. x 10^{-6}	Plant Type 2/	Financing 3/		Net Income Before Taxes $ x 10^{-6}
Case I	a	19.8	M-C	A, 7.25		- 1.2
	b	19.8	"	"		- 0.8
	c	19.8	"	"		- 0.4
Case II		22	M-C	A, 6.53		+ 1.8
Case III		18	M-C	A, 7.98		- 4.9
Case IV	a	19.8	M-C	E	4/	- 0.2
	b	19.8	"	E		+ 0.2
	c	19.8	"	E		+ 0.6
Case V	a	19.8	M-C	A, 7.25		- 1.1
	b	19.8	"	"		- 0.7
	c	19.8	"	"		- 0.3
Case VI	a	30	VDH	A, 7.25		0
	b	30	"	"		+ 0.7
	c	30	"	"		+ 1.2
Case VII	a	30	M-C	A, 7.25		- 0.7
	b	30	"	"		- 0.1
	c	30	"	"		+ 0.5
Case VIII	a	30	M-C	A, 7.25	5/	- 0.1
	b	30	"	"		+ 0.5
	c	30	"	"		+ 1.1

1/ a) The source or collector is paid 2¢ per gallon.
b) The source or collector is paid 2¢ per gallon, but the program is supported by a 2¢ per gallon subsidy.
c) The source or collector is paid 2¢ per gallon, but the program is supported by a 4¢ per gallon subsidy.

2/ M-C = Mechanical-Chemical VDH = Vacuum Distillation-Hydrofining

3/ A = Amortization, Interest Rate on Capital Debt. E = Equity.

4/ Private Investment of Capital.

5/ Product sales price increased 2.8¢ per gallon.

$0.20 per gallon (Case I) while the expanded plant produced fuel at a breakeven price of $0.15 per gallon (Case VII). While some of the observed reduction is due to the receipt of "preferred" feedstock, the dramatic drop in cost is also a function of the fact that fixed operating costs are now spread over 50 percent greater volume of throughput. The formulation for breakeven price does not include revenues from sales of product and, therefore, is a function largely of system costs. This indicates that a regional plant could result in greater cost efficiencies, since available feedstock volumes would be greater.

2. Initial Cost of Plant

The initial cost of the mechanical-chemical plant is $5.7 million at the nominal capacity of 20 mgy. This is reflected in the impact of cost of investment capital. At the same rates of interest, the effect on the cost of the products produced is approximately 1.25 to 1.40¢ per gallon of product produced for every $100,000 of cost of investment.

Any significant reductions or additions in construction costs of a plant will have a similar impact on the cost per gallon of product. This is apparent after reviewing Cases VI and VII wherein the two 30,000,000 gpy plants had respective installation costs of $5.7 and $6.6 million. At a 7.25 percent interest rate, the cost of investment capital for the two plants were $986,364 and $1,333,206, respectively. This is commensurate with 1.8 to 2.1¢ per gallon of product produced due to this variable alone.

3. Rate of Interest on Invested Capital

Cases I and IV are identical except for the interest rates which are 7.25 percent and 0.0 percent per annum, respectively.

The costs due to interest are approximately $414,000 per year, calculated as simple interest. This is equivalent to more than 3.3¢ per gallon of product, or about 0.46¢ per gallon, per percent of interest.

It is clear that the cost of money could have a significant bearing on the cost of product produced. For example, use of industrial bonds for pollution control such as are available in Pennsylvania, which make money available at 5.0 percent interest, would decrease the cost of product by about 1¢ per gallon.

4. Size of Subsidy

In six of the eight cases considered, costs were adjusted by paying for waste oils delivered to the plant or receiving a subsidy of 2 to 4¢ per gallon, i.e., -$0.02 to +$0.02. The impact of the subsidy is approximately 3¢ per gallon of product produced for both the 20 and 30 million gpy plants. All the cases indicate a need for a subsidy varying from 8¢ per gallon to 2.8¢ per gallon of product produced for 1972 fuel costs (not including Cases II, III and IV), and a value ranging from 5¢ per gallon of product produced to zero, based on product values postulated for 1975 through 1977.

5. Bottoms Incineration Capability

The impact of selling process plant bottoms, thus eliminating the need for one incinerator, appears to have little impact on the cost per gallon of product generated. Comparing Cases I and V, eliminating the "bottoms incinerator" results in about a 1¢ per gallon reduction in the breakdown sales price.

It appears, however, that elimination of a bottoms incinerator may be only a temporary possibility since lead-free automobile fuels will become more abundant during the 1975 to 1980 and later time period eliminating the possibility of recovering lead from this source. On the other hand, other products may be developed in the interim.

6. Depreciation

As in other business ventures, "depreciation" serves to decrease the amount of taxes paid by decreasing the "net profits before taxes." At that time, its impact is directly related to the magnitude of the allowed depreciation value. For every $200,000 in depreciation, the impact is approximately 0.5¢ per gallon for the Base Plant on the basis that taxes will be at the 50 percent level, when they do apply.

This indicates that subsidies can also be in the form of accelerated depreciation rates, in addition to more direct payments, to provide a greater rate of return on investment.

7. Quality of Source Material

The impact of feedstock quality on costs, revenues and profits is reflected by the results of analyses for Cases I, VI and VII. In Case I, the general spectrum of waste oils is delivered to the plant, including difficult-to-process oils as well as those that are easily recoverable. An overall plant efficiency of 0.775 is used, i.e., gallons of product out divided by gallons of feedstock processed.

In Cases VI and VII, waste oils from out-of-State sources are obtained. These are a better grade of waste oils, leaving the more difficult and non-recoverable oils for the source state to dispose of.

The vacuum distillation plant cannot handle as broad a spectrum of waste oils as the mechanical-chemical plant. Its overall process plant efficiency is only 0.757 compared to that of 0.775 in Case I. Conversely, the effect of the "selective" grades of oil is to increase the expanded mechanical-chemical plant efficiency to 0.834, a 7.6 percent increase over Case I and 10 percent increase over Case VI.

The impact is such that even though the construction costs are higher for the expanded Case VII plant than for the Case I plant, the average breakeven sales price is 5¢ per gallon less for the big plant.

It therefore becomes important to optimize the degree of segregation of waste oil types to the point where the plant efficiency is maximized without an undue penalty with respect to the costs for segregation.

8. Price of Product

The impact of the price which may be charged for the product is reflected directly on the net profit before taxes. A three-cent increase in fuel oil prices will result in substantial increases in profits. This can be seen by comparing Cases VII and VIII.

Product value will make the difference between a plant being profitable and requiring a subsidy, in almost all cases.

9. Type of Product

The alternatives which have been considered do not provide a ready comparison between lube oil and fuel oil production. Although base lube oil stock has a considerably higher market value than an equivalent volume of fuel oil, a given process plant can produce less lube oil than it can fuel oil. That is, lube oil production efficiency is significantly less than that for fuel oil.

Lube oil is about 64 percent more valuable than fuel oil. Shifting the proposed MES waste oil processing facility to predominantly lube oil production could lead to an increase in net profit. This is partially borne out by comparing Cases VI and VII. Production of lube oil would require an increased capital expenditure for the mechanical-chemical plant.

In summary, cost centers have been identified and sensitivity analyses have been performed. These have helped in the design of the Waste Oil Recovery System. As many "cost centers" as possible should be further identified and additional sensitivity analyses should be performed to determine the greatest positive impact on the cost of producing various products as the program proceeds from one phase to next utilizing the data developed from the program itself.

In addition to the above effects on waste oil recovery and reuse programs, the positive impact of the program on cleanup costs for spilled crankcase or industrial lubricating oils should be discussed.

Data on frequency, type, and size of oil spills were provided by the Maryland Port Authority for oil spill recovery operations over a 16-month period. The cost of cleaning up these various sources and quantities of oil is of the order of approximately $200,000 per year, or almost $14 per gallon.

On the basis that approximately 50 percent of the oil spills may be convenience or unknown spills (i.e., the source has no disposal site or does not wish to pay for disposal), this amounts to a sum of $100,000 per year that can be saved. If the basis of 50 percent is correct, this amount, if ascribed to the processing plant, could have an impact up to 0.8¢ per gallon on products produced.

It can be assumed that an MES waste oil and recovery and reuse program that includes permit requirements, monitoring and compliance programs, plus the various incentives which may possibly be associated with WORRP, will practically eliminate the convenience spills as a means of waste oil disposal.

SECTION VIII

LEGISLATIVE AND PROGRAM MANAGEMENT NEEDS

In order to ensure a cost effective and efficiently operated system, it will be necessary for the State of Maryland to initiate the waste oil recovery and reuse program and to play a continuing role in it. Specifically, the role is defined as follows:

1. To ensure that all sources of waste oil are collected and accounted for, to the maximum extent possible;
2. To the maximum extent possible, ensure that all collected waste oils are delivered to an MES facility, or a State-approved facility in Maryland, or a facility outside the State approved by the receiving state;
3. To implement a continuing management function, including permits, monitoring, and possibly financing;
4. To require that all waste oils delivered are reprocessed or disposed of in an environmentally acceptable manner; and
5. To participate financially to the extent necessary and reasonable to attract private investment.

In general, the legislation exists which will permit the implementation of a waste oil recovery and reuse program. However, some revisions to certain regulations will be required in order to result in an effective program. These requirements are as follows:

1. To ensure that all sources of waste oil are collected and accounted for ---

The Maryland State Department of Natural Resources, in Section II.A of Rules and Regulations, 08.05.04.02, already has sufficient authority to require all those engaged in oil collection, storage, transport, reprocessing, and marketing to obtain a "permit" to operate.

Unless given a rigorous interpretation, Section II.B may be ambiguous for oil collection and transfer, in that it requires an owner or operator to be "adequately equipped to prevent oil pollution and to control oil spills, and has the capability to handle oil in accordance with this regulation and without discharge into waters of the State".

The interpretation or rewrite of this section of the regulations should include provisions for reporting and delivery to an MES facility or other approved facility (i.e., by other State agencies) and to have adequate spill protection and cleanup at all transfer points (even truck-to-truck).

In partial fulfillment of requirements for a "permit", a collector should be required to maintain detailed records of his collections and to provide MES with any requisite data on a regular basis.

In order to verify the accuracy of collection information, the numerous sources should participate in the program also. As all sources are involved in at least oil receiving and waste oil removal, they would fall within the requirements of Section II.A(1) which states: "A permit is required, in accordance with the provisions of this regulation for the operation of an onshore facility when it involves the transfer of oil to or from any truck, tank, transport or tank car", and Section VI(A) which states: "This section applies to any commercial or industrial operation involving the handling of oil regardless of the nature, size, or location of the operation".

The existing application for an "Oil Handlers' Permit" is inadequate for waste oil collection needs. Another permit application should be prepared explicitly for waste oil collection, transport, storage, transfer, data retrieval, monitoring, and compliance needs.

2. To the maximum extent possible, ensure that all collected waste oils are delivered to an MES facility, or a State-approved facility ---

In order to justify any investment in facilities to store, process, and dispose of waste oils, it is necessary to assure an effective use of that investment. If construction and/or operation is based on a private investment, then the private investor must be assured that a sufficient quantity of feed stock (in this case, "waste oil") is available to process into a useable product.

A State-owned and operated facility may operate at a loss on the assumption that waste oil recovery is a State problem, equally distributed throughout the State. Also, a loss may be assumed to be attributable to environmental quality control. The loss may then be recovered by taxation or other means for cost recovery.

Currently, it has been determined that waste oils are being collected and:

a) Delivered out-of-state for burning as a fuel oil after having been diluted with virgin fuel oil, or delivered directly as waste oil;

b) Burned in Maryland;

c) Used for dust control on roads and other areas;

d) Shipped out-of-State to be reprocessed as a base lube stock;

e) Dumped onto the ground as convenience discharges; and

f) Discharged to sewers and storm drains as convenience discharges.

Limit Burning of Lead-Contaminated Waste Oil

Burning of waste oils has received much attention in recent years. Results of burning tests conducted for the American Petroleum Institute in the Task Force on Used Oil Disposal indicate varied results with regard to both burning equipment and stack emissions. Estimates of the amount of lead in waste oil vary from about 0.8 percent to 1.2 percent. A rule-of-thumb value developed by the Association of Petroleum Re-Refiners as a result of sampling large quantities and ranges of types of waste oils appears to be approximately 1000 lbs. of lead per 10,000 gallons of crankcase oil drainings (Association of Petroleum Re-Refiners, Letter Report, February 11, 1970).

It appears that approximately 50 percent of the lead is emitted to the atmosphere with the remainder in the ash or as a build-up on heat exchange surfaces and resulting in decreased heat transfer efficiencies. Recent tests conducted by ESSO Research and Engineering Company for the State of Massachusetts indicate that approximately 80 percent of the lead in the waste oil is discharged into the atmosphere (Waste Oil Reprocessing, January 1973). Of this amount, approximately 95 percent of the lead appeared as particulate matter and was in the sub-micron particulate size range. The testing program was conducted on a fire box type boiler. It was inferred that a water tube boiler would remain at a high efficiency longer than a fire tube boiler, but stack emissions would be still higher from a water tube boiler due to the greater burning efficiency.

However, the following observations may be made:

a) Waste oil is a source of energy during a period clearly affected by petroleum products shortages;

b) Direct burning of waste oils with large volumes of virgin products may not result in unacceptable environmental effects in certain areas;

c) Adverse effects on burner equipment of diluted waste oils may be acceptable from a maintenance point of view ;

d) Burning facilities equipped with adequate air-cleaning systems will be able to utilize waste oils without adverse environmental effects;

e) All types of burning equipment cannot utilize waste oils because of detrimental effects on the equipment and because of emissions of heavy metals; and

f) Without adequate air cleaning equipment, fallout of heavy metals and subsequent assimilation may result in an environmental health hazard.

In order to control the sale of contaminated waste oil as a fuel oil without the knowledge of the specific customer, the customer must be informed by the supplier that the material being received is fuel containing a stipulated fraction of waste oil.

The customer should be informed because the waste oil or waste oil mixtures may cause operating difficulties in burners and result in increased maintenance requirements, and heavy metal emissions may result from improperly controlled stacks.

Burning tests and evaluations should be pursued as an alternative for waste oil disposal.

Controls for Out-of-State Shipments

Shipping out-of-State may be permitted by Maryland if the interstate transporter is licensed by Maryland, and if the means for processing, handling, and disposition are also approved by the receiving state. Transfer points or temporary storage or transfer facilities should likewise be suitably licensed. Furthermore, as a permit condition, all collectors must agree to pick up all sources of waste oils, and all long-distance waste oil haulers must also agree to transport all the classes of waste that are picked up by the local collectors. Failure to comply could be controlled by provision for revocation of an operator permit.

If the out-of-State shipment alternative could be applied totally for all waste oils, the State of Maryland will have had its waste oil problem resolved at minimum cost and with no need for any capital investment for processing and disposal facilities.

If the out-of-State movement of waste oils is not controlled, there will be an inadequate supply of feed stock for satisfactory operation of the reprocessing facility, and Maryland will be forced to handle only those sources of waste oils that require relatively more costly processing or which must be incinerated or disposed of by other means. Additionally, a resource is lost for reuse within the State.

If only the easily reprocessable oil is shipped out-of-State, and all the non-recoverable oil remains within the State for handling and disposal, the capital investment for storage, processing, and disposal facilities will be of the order of $2 to $3 million. Unit operating costs for this fraction of waste oils are relatively high. Since revenues are predicated on the sources being billed by MES for the disposal services, the State would have to provide the identical management services for this concept as it would for other alternatives. This cost would have to be borne by the remaining sources, or MES would have to impose a fee on the sources collected for out-of-State delivery. Consideration should therefore be given to imposing a fee on all waste oils collected in Maryland and delivered directly to out-of-State users. This fee would be used to defray the costs for managing the entire Waste Oil Recovery and Reuse Program.

Financial Incentives

The most effective means for insuring delivery of waste oils to a State receiving facility is associated with financial incentives. If Maryland would pay collectors a somewhat greater fee than could be had from out-of-State purchasers, the waste oil supply would undoubtedly come to a Maryland facility. On the basis of the financial analyses performed, the overall cost of the program will initially be greater than the various sources of revenue expected from product sales, and this will continue to be the case until high plant throughput is achieved.

The State could implement a subsidy philosophy through one of the following alternatives:

a) Maryland could subsidize the program from available funds and treat this subsidy as a cost for pollution control and resource recovery; or

b) Maryland could impose a fee on all virgin oils delivered within the State.

The amount of additional revenue required is dependent upon the current development phase of the program:

Phase I --	Interim Phase - does not include a plant for reprocessing
Phase II --	The plant is operating, but at less than design capacity (if Phase I does not prove adequate)
Phase III --	Plant operating at design capacity
Phase IV --	Expanded plant for greater throughput using same administrative and operating personnel, plus minor capital investments

During Phase I, oil is collected and delivered to an MES facility. MES analyzes and stores the oil, and manages the overall system. The collected oil is sold to out-of-State re-refiners or acceptable in-State consumers. MES pays the collectors for delivering all oils, pays for disposal of non-recoverable oils, sells usable waste oils and bills the various sources for disposal services of the non-recoverable fractions. A modification of this alternative is to leave the existing system as it is (handling largely those waste oils which have a reuse potential) and provide a service for disposal of those waste oils which are non-marketable by the source. However, since only a fraction of the recoverable oils are currently being picked up, this fraction of the resource could not be recovered.

From the data collected and the financial analyses conducted during this study, MES would pay the collectors an average of about 2 to 3¢ per gallon for all sources of waste oils. MES management services would impose another 2 to 3¢ per gallon onto the costs for collection. Waste oil can be sold to several re-refiners located within 200 miles of the proposed central facility site for approximately 3¢ per gallon.

Revenues of 6 to 8¢ per gallon can be obtained if the waste oil can be directly utilized as a fuel with appropriate air pollution controls.

Without direct consumption, it appears that a subsidy of 1 to 3¢ per gallon of waste oil would be required to cover all the costs for operating WORRP during the interim phase. With direct consumption as a fuel, a subsidy may not be required.

During Phases II through IV, the financial analyses indicate a need for additional subsidies due to the large capital investment and the number of personnel required to operate a complete storage, processing, and disposal complex, coupled with a relatively low volume of throughput during the initial months of operation. It is not until the plant reaches a capacity greater than 20 million gallons per year (in 1975) that the need for a subsidy diminishes or disappears. (Refer to Section VII for detailed analyses of capital and operating cash flow, costs and profits during the various stages of the program and for various plant throughputs.)

For example, a waste oil collection and disposal fee of 1¢ per quart on all virgin lubricating oil sold within the State could be imposed. On the basis of U.S. Bureau of Census data, Maryland utilized some 43 million gallons of automotive and industrial lubes during 1969. Even with no increase this volume would produce a revenue of $1,720,000. This study shows that this volume of virgin oil produces approximately 13 million gallons of waste oils. A modification could be 2¢ per quart for automotive lubes and 1¢ per gallon for industrial lubes which would produce revenue of slightly less than $1,000,000.

A waste oil collection and disposal fee of 1¢ per quart will be adequate to reimburse the collectors, provide the necessary MES services immediately at the outset of the WORRP, and subsidize the early phases of the reprocessing and disposal aspects of the program.

The fee assessment method of resource recovery and pollution prevention is operating successfully in Germany, where it was initiated in 1970. Such a program, conducted in Maryland, could have similar benefits. Based upon an average motorist mileage accumulation of 15,000 miles per year, oil changes every 3,000 miles, and addition of make-up oil every 1,000 miles, the costs to the individual motorist would be of the order of 35¢ per year.

It would appear that various sections of the existing MES enabling legislation provide the necessary powers to recover costs by imposing fees for services rendered. For example:

> Section 4(k): Provision is made for "Rates, fees and charges" and "To fix, alter, charge and collect rates, fees, and charges for use of or for services furnished by its projects".
>
> Section 5(g): After establishing a five-year plan, "the Service shall enter into contracts with municipalities and persons within a service district and stipulate...the charges to be apportioned to the municipalities and persons [and] the manner of repaying the Service for these charges...."
>
> Section 7(a): As determination of contract charges and costs "...the Service shall require that the charges reflect the full costs of projects... and to the extent deemed reasonable and practicable by the Service, charges shall also be based on...the volume and characteristics of the wastes as they influence transportation, purification, final disposal, and time pattern of discharge."
>
> Section 4(m)(2): "To make and enter into all contracts or agreements, as the Service determines, necessary or incidental to the performance of its duties....relating to... the use by the Service of the services or facilities of any solid wastes system, or liquid waste system owned or operated other than by the Service; the contract may provide for the collecting of fees, rates, or charges for the projects provided by the Service...".

Section 9 indicates that the Secretary of Natural Resources can request a waste oil recovery program, and that costs for the program "shall be borne by the person against whom...the order was issued...and that the Service shall determine...the costs, rental charges or other fees to be paid by the person to the Service."

MES would use these funds to pay the collectors directly for all waste oils delivered to the State facility. It would replace the fee the collector charges each source for pickup. This mode of operation will induce the collector to pick up all oil sources and deliver these oils to the State facility. Care must be exercised to include specifications for waste oil quality and source identification lest the collector mix incompatible sources or add unwanted volumes to increase the volumes delivered.

3. To implement a continuing management function ---

The activities, services and facilities which must be provided in a total Waste Oil Recovery and Reuse Program include:

a) Collection
b) Receiving
c) Intermediate storage
d) Central storage
e) Processing
f) Product marketing
g) Non-recoverable waste oil handling and disposal
h) Disposal of reprocessing plant bottoms
i) Off-site process residue disposal
j) Wastewater treatment
k) Dispatching
l) Analytical services
m) Computer operation for - billing, processing, and compliance

Management alternatives are presented in Table 28.

Each alternative for most of the cost centers that include private participation requires monitoring. For example, if the collectors get paid per gallon of waste oil, the product they deliver must be analyzed and matched against specifications, or the original waste oil may be diluted with water or incompatible additives.

Table 28. MANAGEMENT ALTERNATIVES FOR A WASTE OIL RECOVERY AND REUSE PROGRAM

Cost Center	Suggested Alternatives
Collection: short haul, long haul	MES could franchise existing collectors or provide MES service with State trucks and drivers.
Receiving Facility	MES could utilize State personnel and sampling facilities or contract to private firms.
Intermediate Storage	MES could lease existing facilities or build MES facilities.
Central Storage	MES could lease existing facilities or build MES facilities.
Processing	MES could build and operate its own facility. MES could build facility and contract for operation. MES could invite private investment for construction of a facility.
Product Marketing	MES could utilize product in State facilities. Private investor could be responsible for product sales.
Non-recoverable Waste Oil Handling and Disposal	MES could contract for disposal at an existing site. MES could construct and operate its own facility. MES could build a facility and contract for operation. MES could invite private investment for construction of a new facility.
Process Plant Bottoms	MES could incinerate in non-recoverable waste oil facility at cost for disposal. MES could incinerate in non-recoverable waste oil facility at no cost.

Table 28 (Continued). MANAGEMENT ALTERNATIVES FOR A WASTE OIL RECOVERY AND REUSE PROGRAM

Cost Center	Suggested Alternatives
Plant Residue Disposal - Off-site	MES or State truck could dispose of to approved site. Contract with private hauling companies.
Wastewater Treatment	MES constructs and operates facility. MES constructs, private contractor operates. Plant constructed and operated by operator of non-recoverable waste oil subsystem.
Dispatching Service	MES , or by contractor under supervision of MES.
Analytical Services Process Billing Compliance	MES, or by contractor under supervision of MES.
Computer Operation Payroll Billing Processing Compliance	MES, or by contractor under supervision of MES.

At intermediate storage facilities, an appropriate sampling program would have to be developed to ensure proper billing to sources and reimbursement to collectors for delivered oil.

Each facet of the program must be analyzed from the special viewpoint of ensuring receipt of the highest quality product possible within the limits of the variability of the waste oils generated.

The two key areas that require further development are the analytical techniques and computer programs.

Analytical Techniques

In all likelihood the range of quality of waste oil from each source would remain within reasonable limits. However, it would be necessary for the collector or processor and MES to be able to document this as the program advances due to the direct impact on reimbursement, processing parameters, products produced, volumes incinerated and the actual billing for each source.

Each collector should utilize a field sampling kit to obtain and analyze samples from each source for comparison with specifications and previous pickups. This would provide a basis for expectations for reimbursement, verification of reimbursement and focusing for subsequent remedial or compliance actions by the source or by MES.

Sampling and/or analytical facilities are required at each storage site for the above mentioned needs.

Each source identification and respective analysis should be logged for subsequent comparison or reference. This can be accomplished with the judicious use of a computer.

Computer Uses

Dispatching collectors, compliance record keeping, billing, waste oil segregation records keeping and assessment, data processing and plant operations, non-recoverable waste oil operating conditions, environmental data logging, economic analyses, sensitivity analyses and accounting are all functions which can be readily computerized.

It is necessary to be able to utilize the computer in a real time mode such as for dispatching collectors for waste oil pickups in the most economical sequence or time frame. It will also be invaluable for billing purposes and for process forecasting. The judicious use of a computer program, and systems, will minimize program costs and personnel required for operations.

4. All waste oils are reprocessed or disposed of in an environmentally-acceptable manner ---

a) Use as road oil.

Tests performed by the Environmental Protection Agency (EPA-R2-72-054, 1972) indicate that the use of waste oils for road oiling results in a significant potential for degradation of surface waters. The characteristics of lube oils and the modifications of various additives included in virgin lube oils are the antithesis of a good road oil. Conclusions from the report indicate:

1) Although the road was oiled in excess of 12 years, only the top one inch of soil had any oil penetration;

2) From on-site and lab investigations, approximately 75 percent of the applied oil soon leaves the road by flotation, following precipitation; and

3) High concentrations of lead were found in the runoff which detrimentally affected receiving waters.

According to the Asphalt Institute, road oiling should be by the application of:

> "...heavy petroleum oil, usually a slow-curing asphalt, to an earthen surface. Under favorable conditions, three or more years of oiling treatments will change an earthen road into a stable, oiled road. Repeated treatments reduce water absorption in the subgrade to a depth sufficient to develop a thickness of road structure that will carry light highway traffic throughout the year..."
>
> "The objective in all road oiling work is a firm,dustless wearing course mat and a strong subgrade layer which will not become saturated with water." (EPA-R2-72-054,1972).

The economics associated with road oiling indicate that it is to the advantage of the users not to use waste oils. Since oiling with waste oils has little if any stabilizing effect on the unpaved road, oiling must be continued indefinitely and the roads must be regraded often. The heavy use of this physically inferior product and the associated labor results in more expense to the user than using an asphaltic base oil designed for road oiling.

In addition to the above, the surface water and ground water quality may be adversely affected by unnecessary contamination by runoff.

In conclusion, Section VII.C of Water Resources Regulation 4.02, Prevention of Oil Pollution, should be revised to remove waste oils "as a binder for unpaved roads".

SECTION IX

IMPLEMENTATION PLAN

INTRODUCTION

This section proposes alternatives by which the State of Maryland may proceed with a phased implementation of a waste oil recovery system to collect, reclaim, reprocess, dispose, and market re-refined oils and by-products. To the extent that it is practical, this system provides for restoration of used lubricants and other oils to their original product specifications, if this is desirable. These re-refined oils would be distributed within the State for use both by State, county, and other public facilities and by private citizens, corporations, and commercial operators.

A preliminary plan and schedule for implementation of such an oil recovery program is included here.

The five basic alternatives shown in Figure 1 imply the setting of policy by the State and definition by the State of those factors and parameters of greatest significance. Briefly, those factors requiring decisions by the State are:

1. The extent of the program,
2. Transportation (State and/or private),
3. Disposal to land, incineration or other (process residues and/or oily wastes),
4. Road oiling with waste oils (control of composition and physical properties),
5. Raw materials -- waste oils (Shall waste oils from outside the State be accepted at the MES Facility? Shall the State cause all waste oil to be brought to the MES Facility?),
6. Products (e.g., fuels vs. lubes),
7. Distribution (Shall products be used only by State facilities? Shall they be marketed within the State and/or externally?),
8. Marketing (Shall the MES market the products? Shall the MES create a marketing organization? Shall the MES put products out for bid sales? Shall the private firms market the products?),

9. Operation and Management,
10. Financing, and
11. Site location.

GENERAL PROGRAM OPTIONS

Five basic options exist for implementation and they are represented by the diagrams in Figure 1.

Option I consists of disposal of waste oils without reprocessing. The exercise of this option requires no reprocessing facility for recovery of fuel or lube oil base stocks. On the other hand, the fraction of this material which is potentially recoverable is lost to reuse. This option does require the construction of disposal facilities, e.g., for incineration or land disposal, or management of the wastes not currently picked up by existing haulers, e.g., burning at existing disposal sites. Program management and partial collection and storage facets are also required.

The Option II alternative includes all collection and management aspects and export out of the State to existing re-refiners. It is possible to expect revenues from the sale of waste oil to the re-refining operators. A partial marketing program is required, and disposal along the lines indicated for Option I is a necessity for those oils not marketable to existing re-refiners.

Option III is the burning of waste oil as a fuel, e.g., at existing power plants, and the incineration or alternate disposal of waste oils. This option preserves partial reuse of waste oil for recovery of heat value which Option I does not. Evaluation of effects on burner equipment and air quality standards should be given further consideration. A marketing program to find uses for unprocessed oils is also a requirement, as well as one of the basic Phase I needs.

Option IV, for the most part, includes the construction and operation of processing and blending facilities and supply of fuel oil. It appears certain, as has been developed in Section IV, that a market exists for use of all fuel oil products to Maryland State Government users, exclusively. A marketing program is required. Option IV preserves the ability to recover the maximum available waste oil reuse potential and to produce higher products, such as lube oil base stocks at a later date. A significant marketing effort will be required to dispose of higher products. Implementation of this option will require the highest capital investment of all the Options.

Option V requires a marketing effort directed to the major oil companies. A disposal program is required in addition, such as that described in Option I.

PROGRAM IMPLEMENTATION

A choice among the options is not required before implementation of the program is begun. All options presented have the collection, storage, and program management needs in common. This suggests that this portion of the program could be pursued immediately while later phases of a potential program are being designed. As such, a collection system operation schematic is presented in Figure 5. The compliance aspects of the program include changes to regulations, a modified permit program, and a logging system to maintain the required program data and information in retrievable form. The monitoring and surveillance include analytical activities for storage sites and collectors and the waste oil quality verification which will determine the fate of each load collected for any of the options. The collection system utilizes existing haulers through a bidding process and with the use of the permit mechanism. The storage system uses existing tank storage capacity on a lease basis after evaluating the current needs for storage and determining the existing capability of tank farms to meet environmental and safety standards.

A possible implementation plan based specifically on the chemical-physical plant design is presented in Figure 6. The plant storage and processing facilities may proceed in three steps as indicated on the figure. Table 28 shows plant capacity data for the various phases shown in Figure 6.

WORRP PROCESSING AND DISPOSAL ALTERNATIVES

Table 30 lists 22 alternative approaches for disposal of waste oils. These alternatives include the four basic options previously discussed. These alternatives can be rated during evaluation of alternatives to develop a program suitable for the State of Maryland, or any other state. Primary advantages and disadvantages have been listed for each.

Coupled with such an evaluation, the range of products which might be produced from a reprocessing facility (shown in Table 31) should be considered.

Figure 5. WASTE OIL RECOVERY AND REUSE PROGRAMS

OPERATIONAL CHART FOR COLLECTION SYSTEM

Waste Oil Source requires pickup

↓

Phones MES State-wide number for pickup

↓

MES operator acknowledges and logs in computer

↓

MES informs collector of pickups on future date

↓

Collector picks up waste oil from source

↓

Collector takes sample at source while pumping out

↓

Both types of sample and total volume are verified by source and collector

↓

Source sends his completed program cards to MES Waste Oil Division for computer log

↓

Collector repeats at each new pickup

↓

Collector delivers load to MES storage facility with his completed program card

↓

MES samples truck contents and verifies receipt of contents

↓

Samples sent for analysis

↓

MES analyzes samples

↓

Compares sample with processing needs and general source characteristics

↓

← ← ← ← ← ← ← ← ← ↓ → → → → → → → → →

MES determines need for compliance or investigation ↓ MES sends data to processing for storage and processing needs

↓

MES sends data to fiscal for payment to collector and fees from sources

Figure 6. PROPOSED MES WASTE OIL RECOVERY PLANT

IMPLEMENTATION PROGRAM

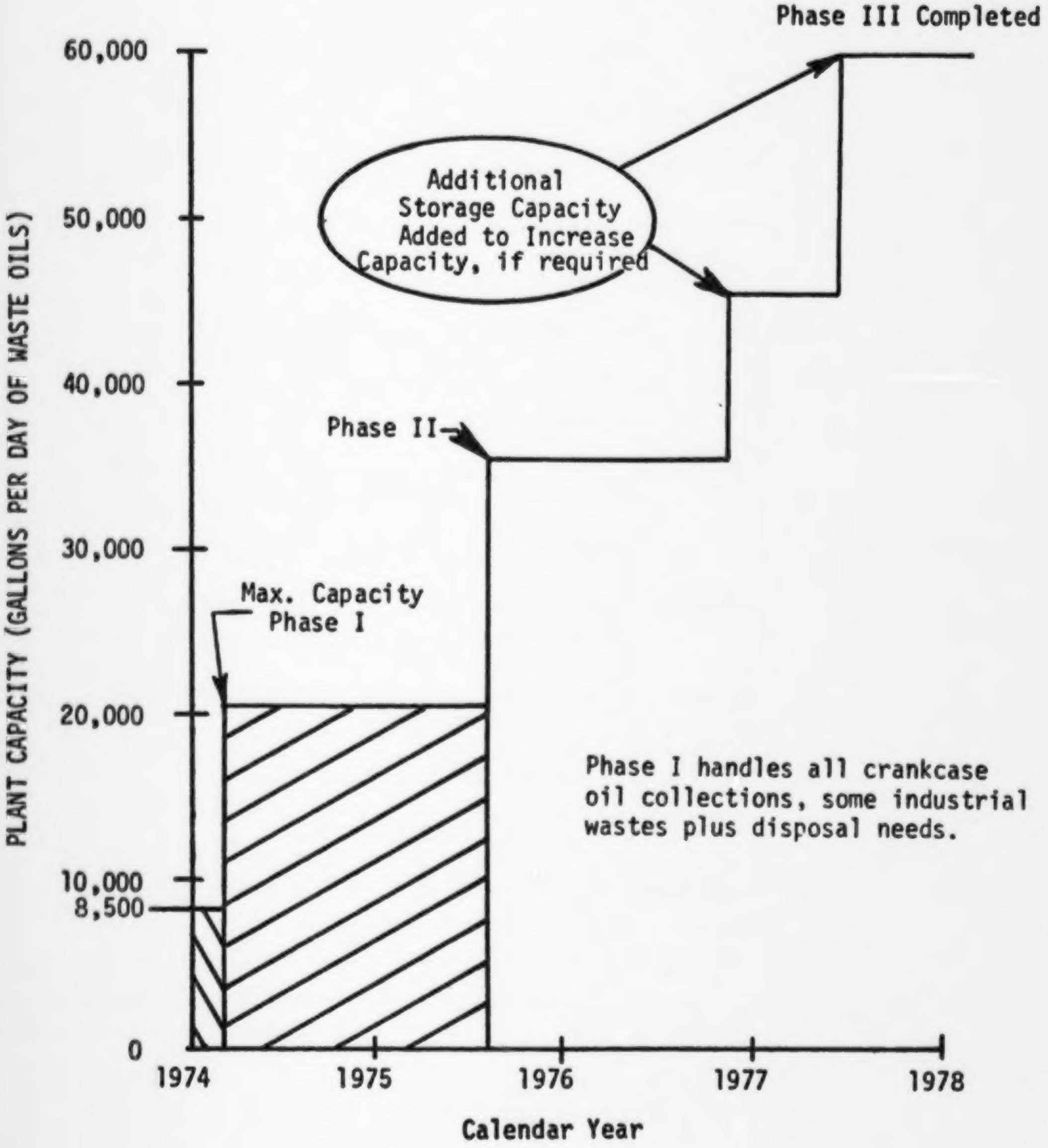

Table 29. PLANT CAPACITY

PHASE I:

Basis: Sequential Production, 8-Hour Day, 5-1/2 days/week

Throughput ~ 8,500 gpd

Expansion of tank farm will permit increased capacity and operating time.

Estimated maximum daily capacity ~ 22,000 gpd; requires 80 percent increase in tankage.

PHASE II:

Basis: Parallel Production, 8-Hour Day, 5-1/2 days/week

90 percent stream factor

Throughput ~ 22,000 gpd

Capacity ~ 36,500 gpd

PHASE III:

Basis: Same as Phase II, except augmented storage capacity

90 percent stream factor - continuous operation

Capacity - maximum of ~ 60,000 gpd.

Table 30. WASTE OIL DISPOSAL ALTERNATIVES

No.	Approach	In Favor Of	Against
1	Leave system as is	Dollars not required.	Does not solve pollution problem. Does not conserve valuable resource.
2	Collect and deposit in abandoned mines or quarries.	Capital & operating costs less than Options III and IV.	Transfers pollution problem to different region. Wastes resource.
3	Incinerate	Capital & operating costs less than Options III and IV.	Wastes valuable materials. Contributes to air pollution. Results in ash containing heavy metals and other toxic materials. Would have to meet new, currently undefined air pollution standards.
4	Dispose to land	Capital & operating costs less than recovery facility.	Wastes valuable materials. Contributes to water pollution.
5	Collect, store in tanks until better alternatives available	Initial capital & operating costs lower than full plant construction. Future solution potentially superior.	Potential costs. Deferred plant could be more costly due to inflation. Seismic or meteorological incident may cause spill.
6	Collect, place in "safe" casks & store underground	Isolates waste from environment.	Potential costs. Accident or seismic incident may cause spill. Wastes valuable material.
7	Pump underground	Isolates waste from environment.	Pretreatment plant cost. Wastes resource. Seismic incident could release materials to environment.
8	Use as fuel directly	Conserves resource. Capital required is less than Options III and IV. Current practice in many locations.	Discharges pollutants to atmosphere. Toxic wastes from burning can pollute water supplies. Does not apply to all oily wastes.
9	Blend with other fuels (and use as fuel directly)	- same as #8 -	- same as #8 -

Table 30 (Continued). WASTE OIL DISPOSAL ALTERNATIVES

No.	Approach	In Favor Of	Against
10	Use as refinery feed	Conserves resource. Returns feed to plants with favorable economics.	Pre-purification can be costly. Refineries cannot accept all oily wastes.
11	Blend with other refinery stocks and use as feed	- same as #10 -	- same as #10 -
12	Collect and use as road oil (dust control)	Capital required less than Options II, III or IV. Conserves resource.	Discharges pollutants to land in uncontrolled manner. Runoff of oil to watercourses.
13	Collect and export out of state	Capital required less than Options III & IV.	State loses potential benefit from waste oils. Exports disposal problems and pollution to another region.
14	Collect, export and receive re-refined products and market in state	Capital requirements less than Options III and IV.	Existing re-refiners cannot renovate all oily wastes properly. Transportation costs. State would have to market in competition with existing suppliers.
15	Collect, build plant, process to fuels and use output in state operations	Capital requirement less than Option IV. State can absorb entire output of fuels with little impact on existing markets. Conserves resource.	Does not convert waste into highest potential product (lubes).
16	Same as #15 - except market output in state	- same as #15 -	Same as #15, and requires State to compete in existing commercial markets. State must create marketing system.
17	Collect, build plant, process to lube stocks and use output in state operations	Conserves resource. Reclaims most original products.	High capital cost option. State facilities cannot use total output. Lube stocks would require blending at point of consumption. Requires State to compete in existing markets.

Table 30 (Continued). WASTE OIL DISPOSAL ALTERNATIVES

No.	Approach	In Favor Of	Against
18	Same as #17 - except market output in State	- same as #17 -	- same as #17 -
19	Collect, build plant, process to finished lube oils and use output in State operations	Conserves resource. Reclaims original products. Blending not required.	Highest capital cost option. State cannot absorb output.
20	Same as #19 - except market within State	- same as #19 -	Same as #19, plus requires State to compete in existing markets. Must penetrate lube oil market by approximately 40 percent.
21	Collect, build plant, process to fuels, lube oils, petrochemical products and other refinery products and market within State	Reclaims original products. Conserves resource.	Higher capital requirements and higher operating costs than #19 and #20. Requires State to compete in existing markets and develop an extensive marketing structure.
22	Implement surveillance and enforcement system	Low capital cost	Long lead time to realize benefits. Potentially higher operating costs than other approaches.

Table 31. MES WASTE OIL DISPOSAL FACILITY

- PRODUCT SPECTRUM -

---

1. Fuel Oils
2. Pre-treated Lube Oil Stocks
3. Pre-treated Diesel Oil Stocks
4. Re-refined Lube Oils
5. Re-refined Transformer Oils
6. Pre-treated Hydraulic Oil Stocks
7. Sterile, Non-toxic Ash
8. Carbon Dioxide & Water Vapor
9. Pre-treated Gear Oil Stocks
10. Pre-treated Turbine Oil Stocks
11. Re-refined Hydraulic Oils
12. Re-refined Cutting Oils
13. Re-refined Quench Oils
14. Process Fuels
15. $CaSO_4$, $CaCl_2$, Heavy Metal Ash
16. Solvents
17. Soap Stocks
18. Feed Additives
19. Process Feed For Others
20. Pre-treated Fatty Oil Stocks

SECTION X

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SECTION XI

APPENDICES

Page

APPENDIX A:
Standard Industrial Classification Categories Receiving Questionnaire 108

APPENDIX B:
Accuracy of the Expression for Distance Between Sources 114

APPENDIX C:
The "Small" Base Plant 119

APPENDIX D:
Waste Oil Recovery Unit Process Evaluations 124

APPENDIX E:
Summary of Collection System Results (PUP-PIP) 137

APPENDIX F:
Pipe Line and Barge Transport of Waste Oils 160

APPENDIX G:
Determining the Size of an Intermediate Storage Storage Tank (IST) 165

APPENDIX H:
Selection of Distribution Regions - Questionnaires 169

APPENDIX I:
Crankcase and Industrial Waste Oil Survey 175

APPENDIX J:
Network Models 184

APPENDIX K:
Summary of Cost, Revenue and Profit (CRP) Model Equations 221

APPENDIX L:
Summary of Cash Flow, Revenue, Profit (CRP) 226

APPENDIX M:
Spills of Oily Material to Baltimore Harbor 243

APPENDIX A

STANDARD INDUSTRIAL CLASSIFICATION CATEGORIES
NOT RECEIVING QUESTIONNAIRE

Table 32. STANDARD INDUSTRIAL CLASSIFICATION CATEGORIES RECEIVING QUESTIONNAIRE

DIVISION A --- AGRICULTURE, FORESTRY, AND FISHING

Major Group 01. -- Agricultural Production - Crops

*Group No. 011 -- Cash Grains
*Group No. 013 -- Field Crops, Except Cash Grains
Group No. 016 -- Vegetables and Melons
Group No. 017 -- Fruits and Tree Nuts
*Group No. 018 -- Horticultural Specialties
*Group No. 019 -- General Farms, Primarily Crop

Major Group 02. -- Agricultural Production - Livestock

*Group No. 021 -- Livestock, Except Dairy, Poultry, and Animal Specialties
Group No. 024 -- Dairy Farms
*Group No. 025 -- Poultry and Eggs
*Group No. 027 -- Animal Specialties
*Group No. 029 -- General Farms, Primarily Livestock

Major Group 07. -- Agricultural Services

Group No. 071 -- Soil Preparation Services
Group No. 072 -- Crop Services
Group No. 074 -- Veterinary Services
Group No. 075 -- Animal Services, Except Veterinary
*Industry No. 0752 -- Animal Specialty Services
*Group No. 076 -- Farm Labor and Management Services
*Group No. 078 -- Landscape and Horticultural Services

*Major Group 08. -- Forestry

Major Group 09. -- Fishing, Hunting, and Trapping

Group No. 091 -- Commercial Fishing
*Group No. 092 -- Fish Hatcheries and Preserves
*Group No. 097 -- Hunting and Trapping, and Game Propagation

DIVISION B --- MINING

*Major Group 10. -- Metal Mining

*Major Group 11. -- Anthracite Mining

Major Group 12. -- Bituminous Coal and Lignite Mining

*Major Group 13. -- Oil and Gas Extraction

Major Group 14. -- Mining and Quarrying of Nonmetallic Minerals, Except Fuels

Group No. 141 -- Dimension Stone
Group No. 142 -- Crushed and Broken Stone, Including Riprap
Group No. 144 -- Sand and Gravel
Group No. 145 -- Clay, Ceramic, and Refractory Minerals
*Group No. 147 -- Chemical and Fertilizer Mineral Mining
*Group No. 148 -- Nonmetallic Minerals (Except Fuels) Services
*Group No. 149 -- Miscellaneous Nonmetallic Minerals, Except Fuels

DIVISION C --- CONSTRUCTION

Major Group 15. -- Building Construction - General Contractors and Operative Builders

*Group No. 152 -- General Building Contractors - Residential Buildings
*Group No. 153 -- Operative Builders
Group No. 154 -- General Building Contractors - Nonresidential Buildings

Major Group 16. -- Construction Other Than Building Construction - General Contractors

Major Group 17. -- Construction - Special Trade Contractors

Group No. 171 -- Plumbing, Heating (Except Electric), and Air Conditioning
*Group No. 172 -- Painting, Paper Hanging, and Decorating
*Group No. 173 -- Electrical Work
*Group No. 174 -- Masonry, Stonework, Tile Setting, and Plastering
*Group No. 175 -- Carpentering and Flooring
Group No. 176 -- Roofing and Sheet Metal Work
Group No. 177 -- Concrete Work
*Group No. 178 -- Water Well Drilling
*Group No. 179 -- Miscellaneous Special Trade Contractors

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* Did not receive Questionnaire.

Table 32 (Continued). STANDARD INDUSTRIAL CLASSIFICATION CATEGORIES RECEIVING QUESTIONNAIRE

DIVISION D --- MANUFACTURING

Major Group 20. -- Food and Kindred Products

Group No. 201 -- Meat Products
Group No. 202 -- Dairy Products
Group No. 203 -- Canned and Preserved Fruits and Vegetables
*Group No. 204 -- Grain Mill Products
*Group No. 205 -- Bakery Products
*Group No. 206 -- Sugar and Confectionery Products
Group No. 207 -- Fats and Oils
Group No. 208 -- Beverages
Group No. 209 -- Miscellaneous Food Preparations and Kindred Products

*Major Group 21. -- Tobacco Manufactures

Major Group 22. -- Textile Mill Products

Group No. 221 -- Broad Woven Fabric Mills, Cotton
Group No. 222 -- Broad Woven Fabric Mills, Man-Made Fiber and Silk
Group No. 223 -- Broad Woven Fabric Mills, Wool (Including Dyeing and Finishing)
*Group No. 224 -- Narrow Fabrics and Other Smallwares Mills: Cotton, Wool, Silk, and Man-Made Fiber
Group No. 225 -- Knitting Mills
Group No. 226 -- Dyeing and Finishing Textiles, Except Wool Fabrics and Knit Goods
*Group No. 227 -- Floor Covering Mills
Group No. 228 -- Yarn and Thread Mills
Group No. 229 -- Miscellaneous Textile Goods

*Major Group 23. -- Apparel and Other Finished Products Made From Fabrics and Similar Materials

Major Group 24. -- Lumber and Wood Products, Except Furniture

Major Group 25. -- Furniture and Fixtures

Major Group 26. -- Paper and Allied Products

*Group No. 261 -- Pulp Mills
Group No. 262 -- Paper Mills, Except Building Paper Mills
Group No. 263 -- Paperboard Mills
Group No. 264 -- Converted Paper and Paperboard Products, Except Containers and Boxes
Group No. 265 -- Paperboard Containers and Boxes
Group No. 266 -- Building Paper and Building Board Mills

Major Group 27. -- Printing, Publishing, and Allied Industries

Group No. 271 -- Newspapers: Publishing, Publishing and Printing
Group No. 272 -- Periodicals: Publishing, Publishing and Printing
Group No. 273 -- Books
Group No. 274 -- Miscellaneous Publishing
Group No. 275 -- Commercial Printing
Group No. 276 -- Manifold Business Forms
Group No. 277 -- Greeting Card Publishing
Group No. 278 -- Blankbooks, Looseleaf Binders, and Bookbinding and Related Work
*Group No. 279 -- Service Industries for the Printing Trade

Major Group 28. -- Chemicals and Allied Products

Major Group 29. -- Petroleum Refining and Related Industries

Major Group 30. -- Rubber and Miscellaneous Plastics Products

Major Group 31. -- Leather and Leather Products

Major Group 32. -- Stone, Clay, Glass and Concrete Products

Major Group 33. -- Primary Metal Industries

Major Group 34. -- Fabricated Metal Products, Except Machinery and Transportation Equipment

Major Group 35. -- Machinery, Except Electrical

Major Group 36. -- Electrical and Electronic Machinery, Equipment, and Supplies

Major Group 37. -- Transportation Equipment

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* Did not receive Questionnaire.

Table 32 (Continued). STANDARD INDUSTRIAL CLASSIFICATION CATEGORIES RECEIVING QUESTIONNAIRE

Major Group 38. -- Measuring, Analyzing, and Controlling Instruments; Photographic, Medical, and Optical Goods; Watches and Clocks

Group No. 381 -- Engineering, Laboratory, Scientific, and Research Instruments
Group No. 382 -- Measuring and Controlling Instruments
Group No. 383 -- Optical Instruments and Lenses
*Group No. 384 -- Surgical, Medical, and Dental Instruments and Supplies
Group No. 385 -- Ophthalmic Goods
Group No. 386 -- Photographic Equipment and Supplies
Group No. 387 -- Watches, Clocks, Clockwork Operated Devices, and Parts

Major Group 39. -- Miscellaneous Manufacturing Industries

Group No. 391 -- Jewelry, Silverware, and Plated Ware
Group No. 393 -- Musical Instruments
Group No. 394 -- Toys and Amusement, Sporting, and Athletic Goods
Group No. 395 -- Pens, Pencils, and Other Office and Artists' Materials
*Group No. 396 -- Costume Jewelry, Costume Novelties, Buttons, and Miscellaneous Notions, Except Precious Metals
*Group No. 399 -- Miscellaneous Manufacturing Industries

DIVISION E --- TRANSPORTATION, COMMUNICATIONS, ELECTRIC, GAS AND SANITARY SERVICES

Major Group 40. -- Railroad Transportation

Major Group 41. -- Local and Suburban Transit and Interurban Highway Passenger Transportation

Major Group 42. -- Motor Freight Transportation and Warehousing

Group No. 421 -- Trucking, Local and Long Distance
*Group No. 422 -- Public Warehousing
Group No. 423 -- Terminal and Joint Terminal Maintenance Facilities for Motor Frieght Transportation

Major Group 43. -- U. S. Postal Service

Major Group 44. -- Water Transportation

Group No. 441 -- Deep Sea Foreign Transportation
Group No. 442 -- Deep Sea Domestic Transportation
*Group No. 443 -- Great Lakes - St. Lawrence Seaway Transportation
Group No. 444 -- Transportation on Rivers and Canals
Group No. 445 -- Local Water Transportation
Group No. 446 -- Services Incidental to Water Transportation

Major Group 45. -- Transportation by Air

Major Group 46. -- Pipe Lines, Except Natural Gas

Major Group 47. -- Transportation Services

Group No. 471 -- Freight Forwarding
*Group No. 472 -- Arrangement of Transportation
*Group No. 474 -- Rental of Railroad Cars
Group No. 478 -- Miscellaneous Services Incidental to Transportation

Major Group 48. -- Communication

Group No. 481 -- Telephone Communication (Wire or Radio)
Group No. 482 -- Telegraph Communication (Wire or Radio)
*Group No. 483 -- Radio and Television Broadcasting
*Group No. 489 -- Communication Services, Not Elsewhere Classified

Major Group 49. -- Electric, Gas, and Sanitary Services

DIVISION F --- WHOLESALE TRADE

Major Group 50. -- Wholesale Trade - Durable Goods

Group No. 501 -- Motor Vehicles and Automotive Parts and Supplies
*Group No. 502 -- Furniture and Home Furnishings
*Group No. 503 -- Lumber and Other Construction Materials
*Group No. 504 -- Sporting, Recreational, Photographic, and Hobby Goods, Toys, and Supplies
Group No. 505 -- Metals and Minerals, Except Petroleum
*Group No. 506 -- Electrical Goods

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* Did not receive Questionnaire.

Table 32 (Continued). STANDARD INDUSTRIAL CLASSIFICATION CATEGORIES RECEIVING QUESTIONNAIRE

*Group No. 507 -- Hardware, and Plumbing and Heating Equipment and Supplies
*Group No. 508 -- Machinery, Equipment, and Supplies
Group No. 509 -- Miscellaneous Durable Goods

Major Group 51. -- Wholesale Trade - Nondurable Goods

*Group No. 511 -- Paper and Paper Products
*Group No. 512 -- Drugs, Drug Proprietaries and Druggists' Sundries
*Group No. 513 -- Apparel, Piece Goods, and Notions
*Group No. 514 -- Groceries and Related Products
Group No. 515 -- Farm-Product Raw Materials
Group No. 516 -- Chemicals and Allied Products
Group No. 517 -- Petroleum and Petroleum Products
Group No. 518 -- Beer, Wine and Distilled Alcoholic Beverages
Group No. 519 -- Miscellaneous Nondurable Goods

DIVISION G --- RETAIL TRADE

Major Group 52. -- Building Materials, Hardware, Garden Supply, and Mobile Home Dealers

*Group No. 521 -- Lumber and Other Building Materials Dealers
*Group No. 523 -- Paint, Glass, and Wallpaper Stores
*Group No. 525 -- Hardware Stores
*Group No. 526 -- Retail Nurseries, Lawn and Garden Supply Stores
Group No. 527 -- Mobile Home Dealers

Major Group 53. -- General Merchandise Stores

Group No. 531 -- Department Stores
*Group No. 533 -- Variety Stores
Group No. 539 -- Miscellaneous General Merchandise Stores

*Major Group 54. -- Food Stores

Major Group 55. -- Automotive Dealers and Gasoline Service Stations

*Major Group 56. -- Apparel and Accessory Stores

*Major Group 57. -- Furniture, Home Furnishings, and Equipment Stores

*Major Group 58. -- Eating and Drinking Places

Major Group 59. -- Miscellaneous Retail

Group No. 591 -- Drug Stores and Proprietary Stores
*Group No. 592 -- Liquor Stores
*Group No. 593 -- Used Merchandise Stores
*Group No. 594 -- Miscellaneous Shopping Goods Stores
*Group No. 596 -- Nonstore Retailers
Group No. 598 -- Fuel and Ice Dealers
*Group No. 599 -- Retail Stores, Not Elsewhere Classified

DIVISION H --- FINANCE, INSURANCE, AND REAL ESTATE

*Major Group 60. -- Banking

*Major Group 61. -- Credit Agencies Other Than Banks

*Major Group 62. -- Security and Commodity Brokers, Dealers, Exchanges, and Services

*Major Group 63. -- Insurance

*Major Group 64. -- Insurance Agents, Brokers, and Service

*Major Group 65. -- Real Estate

*Major Group 66. -- Combinations of Real Estate, Insurance, Loans, Law Offices

*Major Group 67. -- Holding and Other Investment Offices

DIVISION I --- SERVICES

Major Group 70. -- Hotels, Rooming Houses, Camps, and Other Lodging Places

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* Did not receive Questionnaire.

Table 32 (Continued). STANDARD INDUSTRIAL CLASSIFICATION CATEGORIES RECEIVING QUESTIONNAIRE

Group No. 701 -- Hotels, Motels, and Tourist Courts
*Group No. 702 -- Rooming and Boarding Houses
Group No. 703 -- Camps and Trailering Parks
*Group No. 704 -- Organization Hotels and Lodging Houses, on Membership Basis

Major Group 72. -- Personal Services

Group No. 721 -- Laundry, Cleaning, and Garment Services
*Group No. 722 -- Photographic Studios, Portrait
*Group No. 723 -- Beauty Shops
*Group No. 724 -- Barber Shops
*Group No. 725 -- Shoe Repair Shops, Shoe Shine Parlors, and Hat Cleaning Shops
*Group No. 726 -- Funeral Service and Crematories
*Group No. 729 -- Miscellaneous Personal Services

Major Group 73. -- Business Services

*Group No. 731 -- Advertising
*Group No. 732 -- Consumer Credit Reporting Agencies, Mercantile Reporting Agencies, and Adjustment and Collection Agencies
*Group No. 733 -- Mailing, Reproduction, Commercial Art and Photography, and Stenographic Services
*Group No. 732 -- Services to Dwellings and Other Buildings
*Group No. 735 -- News Syndicates
*Group No. 736 -- Personnel Supply Services
*Group No. 737 -- Computer and Data Processing Services
Group No. 739 -- Miscellaneous Business Services

Major Group 75. -- Automotive Repair, Services, and Garages

Major Group 76. -- Miscellaneous Repair Services

*Group No. 762 -- Electrical Repair Shops
*Group No. 763 -- Watch, Clock, and Jewelry Repair
*Group No. 764 -- Reupholstery and Furniture Repair
Group No. 769 -- Miscellaneous Repair Shops and Related Services

*Major Group 78. -- Motion Pictures

*Major Group 79. -- Amusement and Recreation Services, Except Motion Pictures

*Major Group 80. -- Health Services

*Major Group 81. -- Legal Services

*Major Group 82. -- Educational Services

*Major Group 83. -- Social Services

Major Group 84. -- Museums, Art Galleries, Botanical and Zoological Gardens

*Group No. 841 -- Museums and Art Galleries
Group No. 842 -- Arboreta, Botanical, and Zoological Gardens

*Major Group 86. -- Membership Organizations

*Major Group 88. -- Private Households

*Major Group 89. -- Miscellaneous Services

DIVISION J --- PUBLIC ADMINISTRATION

DIVISION K --- NONCLASSIFIABLE ESTABLISHMENTS

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* Did not receive Questionnaire.

APPENDIX B

ACCURACY OF THE EXPRESSION FOR DISTANCE BETWEEN SOURCES

ACCURACY OF THE EXPRESSION FOR DISTANCE BETWEEN SOURCES

The expression for distance between sources used in the collection model is:

$$d_z = \sqrt{\frac{A_z}{m_z}} \qquad (11)$$

where: A_z = The area of the collection region

m_z = The number of sources in the region

This calculation assumes a row and column distribution of sources throughout the region with equal distance between sources. The distance d_z then represents the orthogonal distance between adjacent sources. This is a conservative estimate in that it tends to overstate the average distance between sources in a given region. The question as to the degree to which this calculation tends to overstate distance is of interest but is impossible to answer in the absence of exact knowledge of the distribution of sources over the region. However, it is possible and illuminating to calculate the degree of overstatement in a case where the sources are spread at random over the region in question. That is, the sources are located as if they were dropped one at a time onto the region's surface with any source being as likely to land one place as another on the surface of the region.

Under these circumstances it may be shown that the probability of two sources being within one segment of area within the region follows the gamma probability law such that the probability of exactly two sources being located within a segment of area, rmi^2, within the region whose total area is Ami^2 is:

$$f(r) = \left(\frac{m_z^2 r}{A_z^2}\right) e^{-\left(\frac{m_z r}{A_z}\right)}$$

The expected or average area containing exactly two sources may now be determined as:

$$E(x) = \int_{-\infty}^{\infty} f(r)dr = \frac{2A_z}{m_z}$$

The question now remaining is how far apart does one expect these two sources to be within this segment of the region z. Let the area $2A_z/m_z$ have width W and height H. Then if X represents the distance of source one from the left side of the area and Y represents the distance from the bottom, the density functions for the random variables X_1 and Y_1 are:

$$f_{X_1}(x_1) = \frac{1}{W} \qquad 0 \leq x_1 \leq W$$

$$f_{x_1}(x_1) = 0 \qquad \text{elsewhere}$$

$$f_{Y_1}(y_1) = \frac{1}{H} \qquad 0 \leq y_1 \leq H$$

$$f_{y_1}(y_1) = 0 \qquad \text{elsewhere}$$

In the same manner we may describe the likelihood of the location of the second source:

$$f_X(x_2) = \frac{1}{W} \qquad 0 \leq x_2 \leq W$$

$$f_{x_2}(x_2) = 0 \qquad \text{elsewhere}$$

$$f_{Y_2}(y_2) = \frac{1}{H} \qquad 0 \leq y_2 \leq H$$

$$f_{y_2}(y_2) = 0 \qquad \text{elsewhere}$$

Define a random variable U such that $U = x_2 - x_1$, the horizontal separation between sources one and two. Then by convolution:

$$f_U(u) = \int_{-\infty}^{\infty} f_{x_1}(x_1) f_{x_2}(u+x_1) d_{x_1}$$

The limits in this case being such that when:

$$-W \leq u \leq 0,$$

$$-u \leq x_1 \leq W$$

and when

$$0 \leq u \leq W,$$

$$0 \leq x_1 \leq W-u$$

This leads to a density function for U of:

$$f_U(u) = \frac{1}{W} + \frac{u}{W^2} \quad \text{when } -W \leq u \leq 0$$

$$f_U(u) = \frac{1}{W} - \frac{u}{W^2} \quad \text{when } 0 \leq u \leq W$$

$$f_U(u) = 0 \text{ elsewhere}$$

The expected value of U^2 may now be calculated as:

$$E(U^2) = \int_{-\infty}^{\infty} u^2 f_U(u) du$$

$$E(U^2) = \frac{W^2}{6}$$

In the same way, the expected square of the vertical separation between the sources is:

$$E(V^2) = \frac{H^2}{6}$$

where: $V = Y_2 - Y_1$

Now, the expected distance between the sources is:

$$E(d) = \sqrt{\frac{H^2}{6} + \frac{W^2}{6}}$$

It is known that the perimeter of a rectangle is minimized for a given area when the length equals the width; i.e., the rectangle is a square. Therefore, the distance E(d) will be less for a square than any other rectangular configuration. Looking at a square then,

$$E(d) = \sqrt{\frac{W^2}{3}}$$

But: $$W^2 = \frac{2A_z}{m_z}$$

Therefore:

$$E(d) = \sqrt{\frac{2}{z}\,\frac{A_z}{m_z}} = .817\sqrt{\frac{A_z}{m_z}}$$

Thus, the expression: $$d_z = \sqrt{\frac{A_z}{m_z}}$$

overstates the average distance between sources by a factor of:

$$1 \Big/ \sqrt{2/3} = \frac{1}{.817} = 1.22$$

or some 22 percent. Increased irregularity of distribution of sources will increase the degree of conservatism of the estimate of d_z used in the collection model.

APPENDIX C

THE "SMALL" BASE PLANT

THE "SMALL" BASE PLANT

The full-scale processing facility which was developed conceptually during the course of the project involves simultaneous processing of waste oils under different treatment conditions. It also would require fairly large capital and operating expenditures. As a possible first step in developing a full-scale processing facility, therefore, cost estimates were made for a scaled-down facility based on:

1. Using selected elements from the full-scale plant.
2. Maintaining the same processing capabilities as the full-scale plant but at a reduced throughput.
3. Incineration of much of the waste oils (non-recoverable) which would have to be incinerated at a full-scale facility.
4. Reducing the necessary plant operating staff from 22 to 17 men.
5. Operating 24 hours/day for about 330 stream-days/year.

The results which follow from postulating such a reduced facility are presented in detail in the preliminary design report. Briefly, throughput is reduced to about 22,000 GPD of waste oil feedstock by taking this approach. Obviously, the overall processing system is no longer comprehensive, and some selectivity can be manifest in accepting feedstock. The following Tables, 33 and 34 , contain brief summaries of capital cost and net profit estimates for this "small" base plant.

Table 33. PRELIMINARY CAPITAL COST ESTIMATE FOR A "SMALL" MES WASTE OIL RECOVERY BASE PLANT*

Basic Process Equipment Costs	$ 570,000
Field Materials (75%)[a]	428,000
Direct Material	$ 998,000
Direct Field Labor (35%)	349,000
Direct Costs	$1,347,000
Direct Tank Farm Costs	565,000**
Indirect Costs[b]	721,000
Bare Module Cost[c]	$2,633,000
Plant Buildings[d]	170,000
Base Plant Cost	$2,803,000
Site Development	176,000
Estimated Total Plant Cost	$2,980,000
Estimated Working Capital	$ 125,000

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* Total costs estimated from "Rapid Calculation Charts", Chemical Engineering, Jan. 13, 1969 for carbon steel. Does not include land costs.

** Installed cost including tank foundations and pumps.

[a] Secondary cost element including piping, instrumentation, foundations and other conrete work, local steel, electrical materials, paint, etc.

[b] Secondary cost element including construction overhead (field supervision, temporary field facilities, small tools, etc.) and engineering and contractor fee (direct engineering labor, overhead office costs, etc.) and interest during construction, owners' costs and 1 month's startup.

[c] This cost does not include site development, pilings, buildings or other offsite facilities.

[d] Laboratory, office, warehouse and shop space, fully equipped.

Table 34. PRELIMINARY DESIGN NET PROFIT ESTIMATE FOR A "SMALL" MES WASTE OIL RECOVERY BASE PLANT

- Fuel Oil Option -

Estimated Capital Cost: $ 2,980,000

22,000 GPD processing capacity plus 8,400 GPD of non-recoverables incineration

330 stream-days/year - - - - - - transport costs recovered by truckers

Yield - - - - - 330 x 22,000 x 0.78 = 5.7 x 10^6 gallons

Fuel Oil - - - - - - 5.7 x 10^6 + 25% = 7.12 x 10^6 gal/yr

Disposal Oils - - - 8,400 GPD x 330 = 2.77 x 10^6 gal/yr

Fuel Price - - - - - - - - 12.2¢/gal.

Disposal - - - - - - - - - 10¢/gal.

REVENUE

Fuel Oils - - - - 7.12 x 10^6 x $0.122 = $ 869,000

Disposal - - - - 2.77 x 10^6 x $0.10 = 277,000

Total = $1,146,000/yr.

COSTS

Equipment and plant lease: $168/year/$1000 of capital investments*

Base of $2.98 x 10^6 implies - - - $500,000/year fixed charges

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* Private communication for 15-year lease.

Table 34 (Continued). PRELIMINARY DESIGN NET PROFIT ESTIMATE FOR A "SMALL" MES WASTE OIL RECOVERY BASE PLANT

LABOR

17 people @ $14,000/year	$238,000/yr.
DLO @ 30%	71,000
G&A @ 15%	36,000
TOTAL	$345,000/yr.

OPERATION

Chemicals	$264/day x 330 days	$ 87,000
Cutter Stock	1.42 x 10^6 gpy x $0.122	173,000
Process Fuel		9,000
Power		20,000
	Subtotal	$289,000
Office G&A @ 10%		29,000
	Total	$318,000

MAINTENANCE @ 2% of Capital	$ 60,000

SUMMARY:

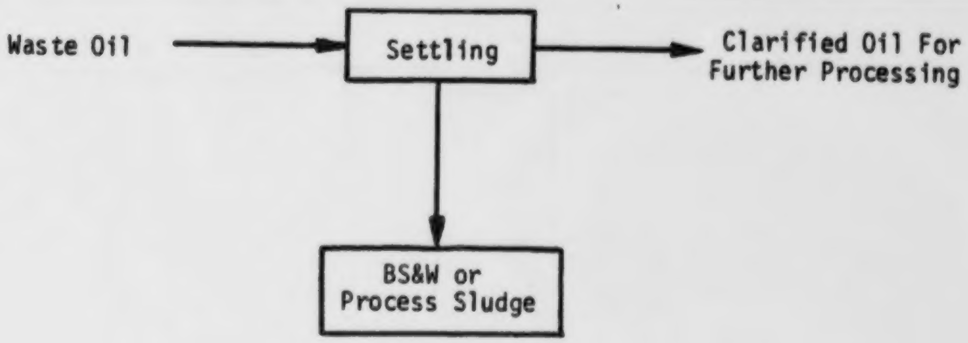
LABOR	$ 345,000
OPERATION	318,000
MAINTENANCE	60,000
O&M Subtotal	$ 723,000
LEASE	500,000
INSURANCE @ 1%	30,000
Total	$1,253,000
Sales Revenue	$1,146,000
Net Profit Before Taxes	$107,000/year DEFICIT

APPENDIX D

WASTE OIL RECOVERY UNIT
PROCESS EVALUATIONS

These charts depict the various processes which may be used to treat waste oil. Each is assessed with a series of "Advantages" and Disadvantages".

Table 35. REMOVAL OF GROSS WATER, COARSE SOLIDS & OTHER MATERIALS HEAVIER THAN THE OIL


Waste Oil
Settling
Clarified Oil For Further Processing
BS&W or Process Sludge

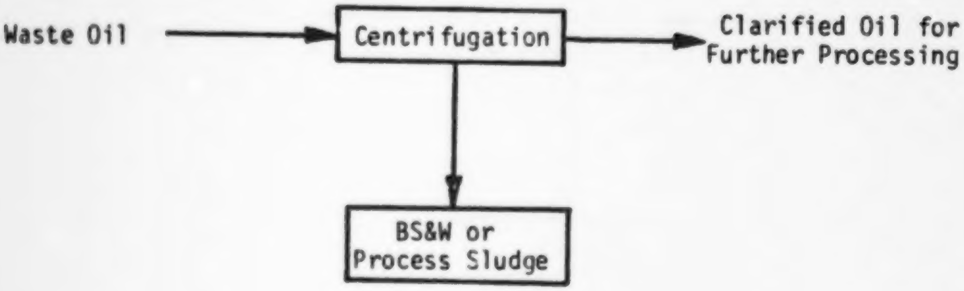
Advantages

1. Standard unit operation.
2. Uses otherwise necessary tankage for processing.
3. Residence times easily adjustable.
4. Low capital & operating costs compared to filtration and stripping.
5. Performance demonstrated.
6. Implementation possible in near future.

Disadvantages

1. Ineffective for very small particles or neutral density materials.
2. Can require long settling times or heating to be effective.

Table 36. REMOVAL OF WATER, SOLIDS & OTHER MATERIALS HEAVIER THAN THE OIL


Waste Oil
Centrifugation
Clarified Oil for Further Processing
BS&W or Process Sludge

Advantages

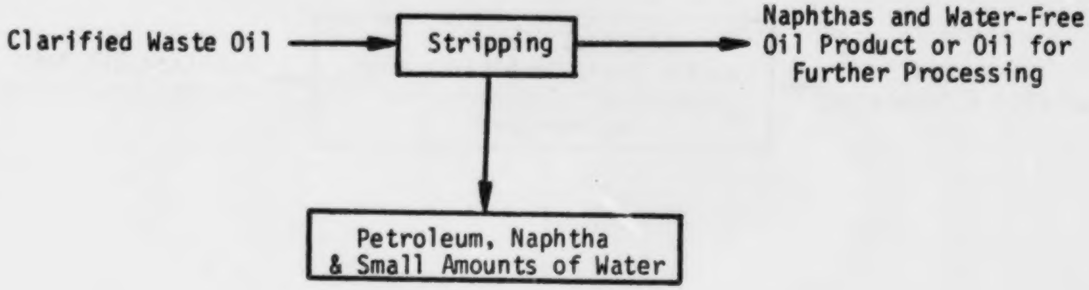
1. Already in limited use.
2. Can remove small solid particles & water droplets from oil.
3. Requires less land area than settling tanks.
4. Rapid processing rate compared to settling.

Disadvantages

1. Higher capital & operating costs than settling and filtration.
2. Performance not well demonstrated.
3. Requires heating or dilution of oil.
4. Additional unit operation as opposed to use of storage tanks for settling.
5. Throughputs and residence times not adjustable over wide ranges of feed characteristics.
6. Not applicable to multi-phase separation.
7. Will require additional testing & evaluation for application to wide range of feed.

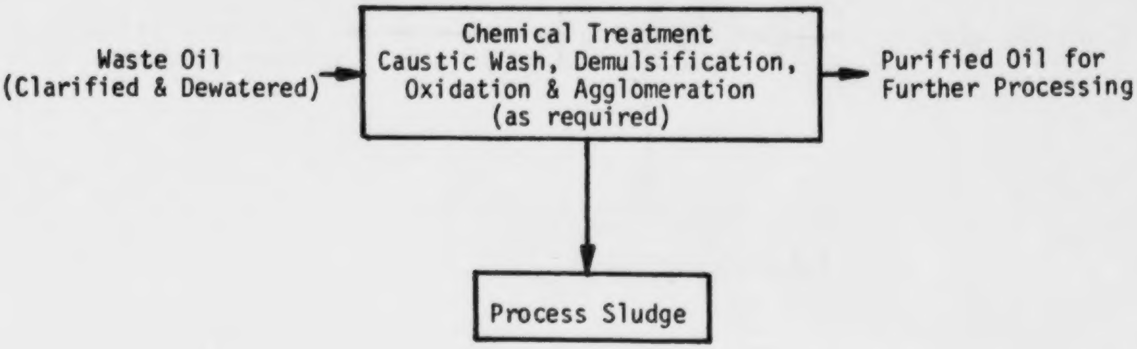
Table 37. REMOVAL OF LIGHT ENDS, NAPHTHA AND WATER

(Between .5 and 5%)


Clarified Waste Oil
Stripping
Naphthas and Water-Free Oil Product or Oil for Further Processing
Petroleum, Naphtha & Small Amounts of Water

Advantages	Disadvantages
1. Demonstrated unit operation.	1. Direct fired heaters for waste oil service require special design.
2. Uses conventional hardware.	2. Such heaters are more costly than comparable refinery facilities.
3. Capital & operating costs lower than solvent extraction or adsorption purification.	3. Coking occurs on furnace tubes and in the still and requires frequent maintenance.
4. Implementation possible in near future.	

Table 38. REMOVAL OF ACIDIC COMPOUNDS, ADDITIVES & CONTAMINANTS STABILIZED IN SOLUTION AND SUSPENSION


Waste Oil
(Clarified & Dewatered)
Chemical Treatment
Caustic Wash, Demulsification,
Oxidation & Agglomeration
(as required)
Purified Oil for
Further Processing
Process Sludge

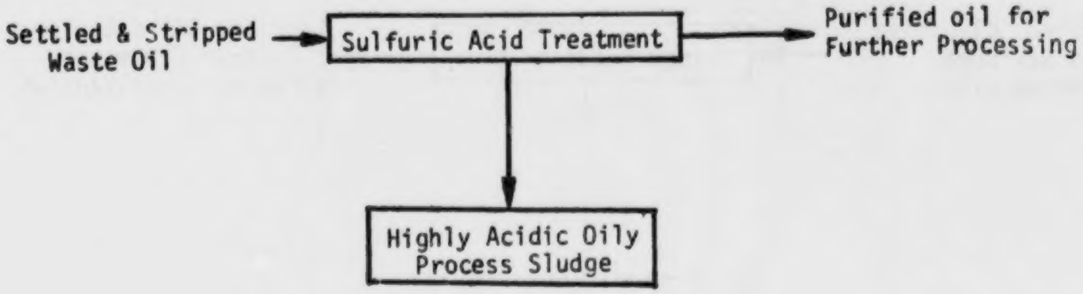
Advantages

1. Can be performed in same facilities with basic settling operation.
2. Implementation possible in near future.
3. Minimizes sludge production by use of small or trace amounts of reagents.
4. Reagents are commercially available.
5. More applicable to wider range of feed characteristics than sulfuric acid treatment.
6. Capital & operating costs lower than solvent extraction.

Disadvantages

1. Process control is complex.
2. Performance not demonstrated.
3. Chemical usage is dependent on feed oil characteristics.

Table 39. REMOVAL OF ADDITIVES & CONTAMINANTS STABILIZED IN SOLUTION AND SUSPENSION


Settled & Stripped Waste Oil
Sulfuric Acid Treatment
Purified oil for Further Processing
Highly Acidic Oily Process Sludge

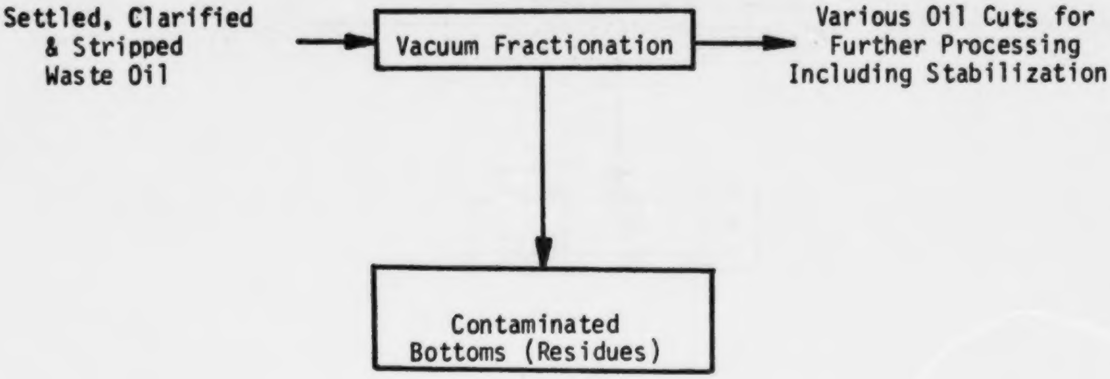
Advantages

1. Demonstrated performance.
2. Implementation possible in near future.
3. Operation of process is straightforward and standardized.
4. Capital and operating costs lower than combination of solvent extraction and fractional distillation.

Disadvantages

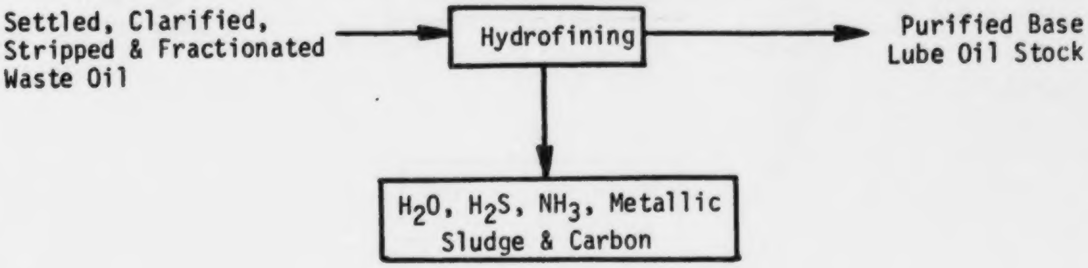
1. Application limited to crankcase or similar oils.
2. Produces large quantities of highly acid waste sludges.
3. Requires sludge disposal program more costly than solvent extraction and distillation process residues.

Table 40. SEPARATION OF HEAVY CONTAMINANTS PLUS SPLITTING OF OIL INTO VARIOUS FRACTIONS


Settled, Clarified & Stripped Waste Oil
Vacuum Fractionation
Various Oil Cuts for Further Processing Including Stabilization
Contaminated Bottoms (Residues)

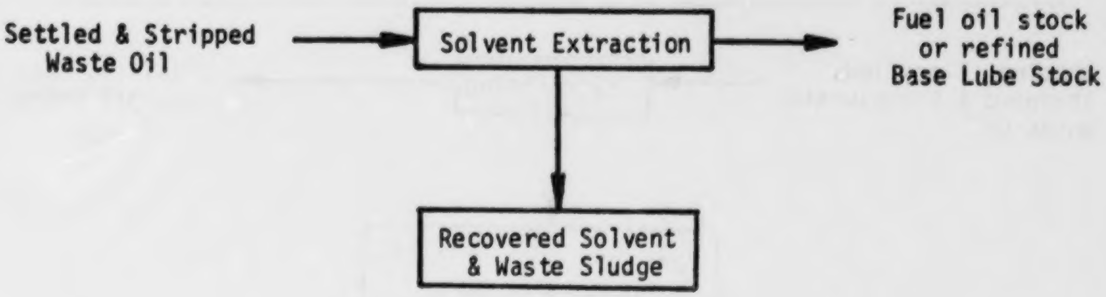
Advantages	Disadvantages
1. Uses available hardware.	1. Produces contaminated bottoms which must be disposed of.
2. Moderate capital and operating costs compared to solvent extraction.	2. High temperature operation required.
3. Capable of producing a range of products.	3. Loss of potential products in bottoms.
4. Implementation possible in the near future.	4. Direct fired heater design and operating problems as with stripping.
	5. Near term application limited to additive and heavy metal-free feed, and feed free of azeotropes.

Table 41. REDUCTION OF NITROGEN, SULFUR & OXYGEN CONTAMINANTS WITH HYDROGEN


Settled, Clarified, Stripped & Fractionated Waste Oil
Hydrofining
Purified Base Lube Oil Stock
H_2O, H_2S, NH_3, Metallic Sludge & Carbon

Advantages	Disadvantages
1. Potential for production of a highly purified base oil stock.	1. Unproven commercial performance for waste oils.
2. Potential of small amounts of process residues	2. Requires special cobalt-molybdenum oxide catalyst.
	3. Catalyst is poisoned by carbon monoxide and contaminants such as chlorine and heavy metals.
	4. May require large amounts of hydrogen.
	5. High pressure/high temperature process.
	6. High capital and operating costs for the basic hydrofining equipment.
	7. Necessary hydrogen plant also would involve additional capital and operating costs.
	8. Implementation is possible only after additional development.
	9. Process operation dependent on the nature of the feed oil.

Table 42. SELECTIVE EXTRACTION OF OIL AND CONTAMINANTS


Settled & Stripped Waste Oil
Solvent Extraction
Fuel oil stock or refined Base Lube Stock
Recovered Solvent & Waste Sludge

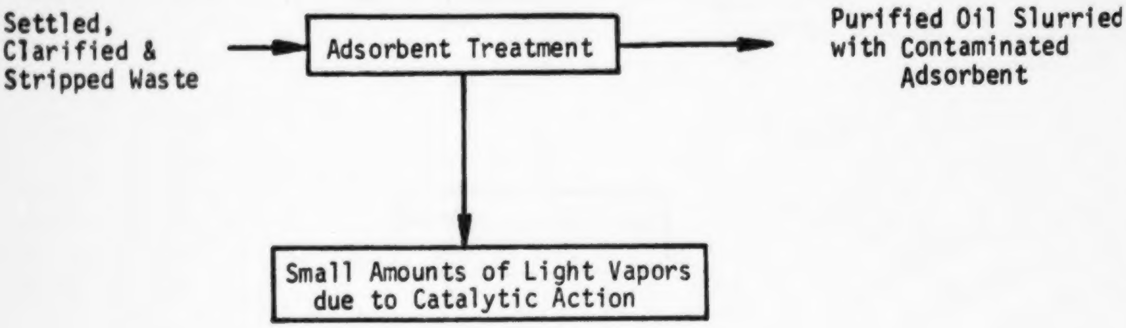
Advantages

1. Demonstrated performance on both full and bench scales (limited on waste oils).
2. Solvent can be selected to suit the feed stock quality.
3. Solvent is recovered for reuse.
4. Implementation possible in near future.
5. Concentrates contaminants.
6. Uses conventional hardware
7. Lower capital and operating costs than adsorptive purification.
8. Some solvents could be produced by the plant.
9. Can be used to break emulsions.

Disadvantages

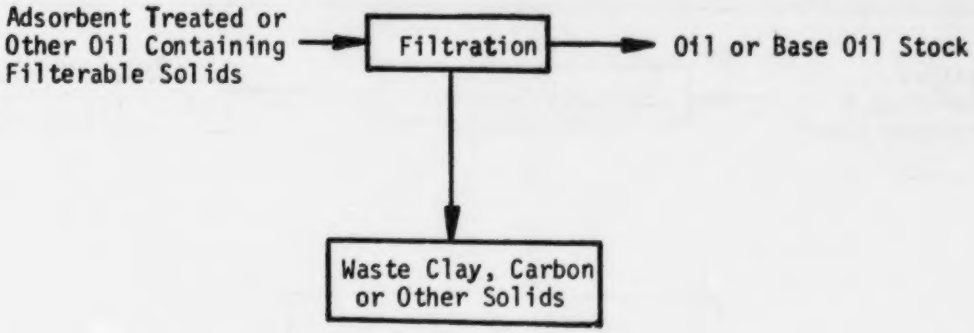
1. Requires additional stripping operations for product, sludge and solvent recovery.
2. Requires sophisticated process and quality control.
3. Can require long settling times in cases where feed and solvent density values are similar.

Table 43. ADSORPTION OF METALLIC SULFURETTED, CHLORINATED & OTHER ADDITIVES PLUS ODOR & COLOR BODIES


Settled, Clarified & Stripped Waste
Adsorbent Treatment
Purified Oil Slurried with Contaminated Adsorbent
Small Amounts of Light Vapors due to Catalytic Action

Advantages	Disadvantages
1. Demonstrated performance in full scale operations (clay).	1. Requires pretreatment and subsequent filtration.
2. Lower capital & operating costs than hydrofining.	2. Adsorbent requires regeneration and/or disposal.
3. Uses conventional hardware.	3. Heater problems similar to stripping.
4. High performance as a finish step to remove trace amounts of contaminants.	
5. Implementation possible in the near future.	

Table 44. REMOVAL OF SUSPENDED & SETTLEABLE SOLIDS FROM OIL


Adsorbent Treated or Other Oil Containing Filterable Solids
Filtration
Oil or Base Oil Stock
Waste Clay, Carbon or Other Solids

Advantages	Disadvantages
1. Demonstrated performance in full scale operations.	1. Adsorbent requires regeneration and/or disposal.
2. Uses conventional hardware.	2. Not applicable to colloidal suspensions and some emulsions.
3. Implementation possible in near future.	
4. Applicable to a wide range of feed quality.	
5. Process operation and control is straightforward.	
6. Capital costs lower than centrifugation and settling.	

Table 45. EXAMPLE PROCESS TRAIN

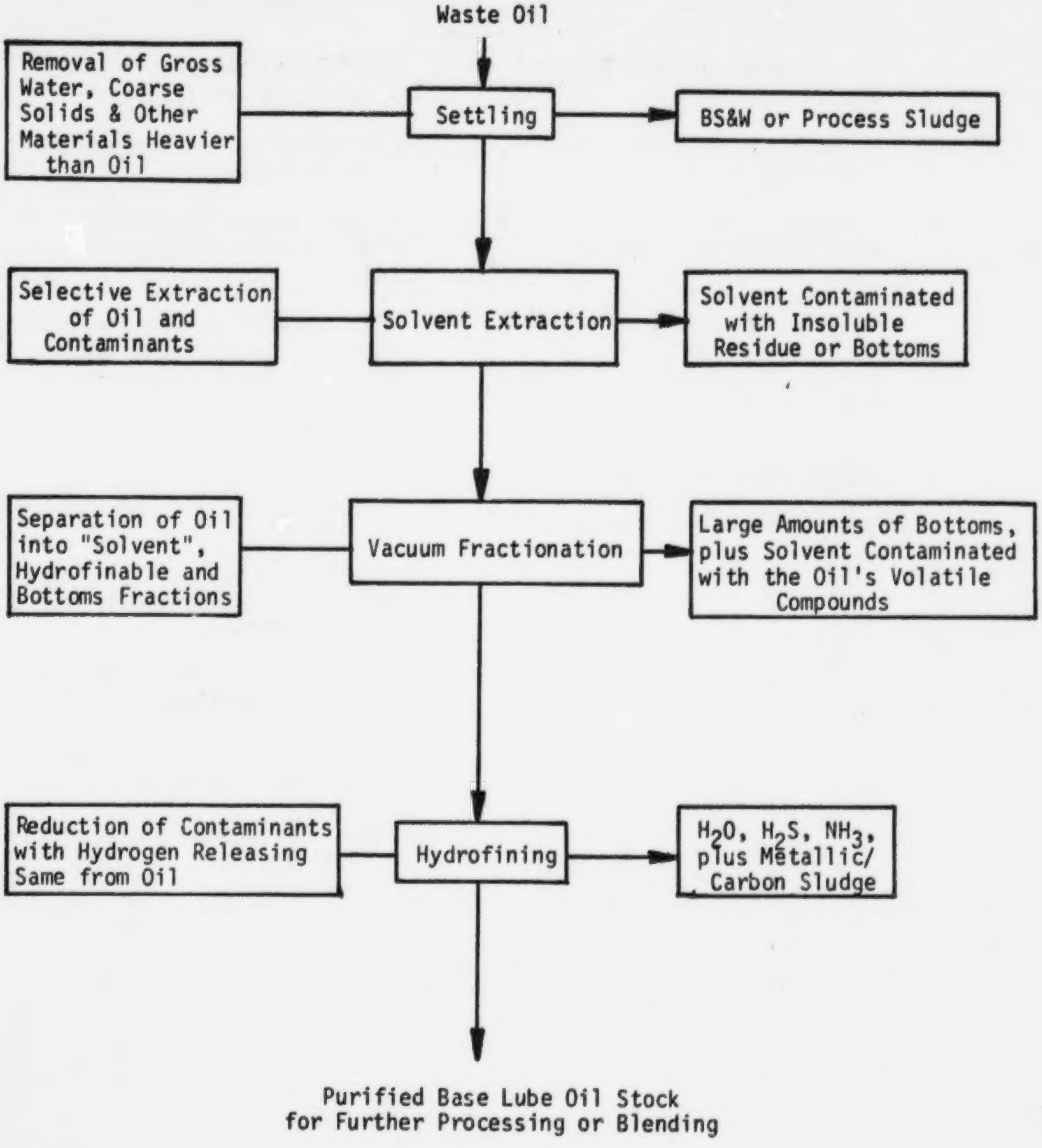

Waste Oil
Removal of Gross Water, Coarse Solids & Other Materials Heavier than Oil
Settling
BS&W or Process Sludge
Selective Extraction of Oil and Contaminants
Solvent Extraction
Solvent Contaminated with Insoluble Residue or Bottoms
Separation of Oil into "Solvent", Hydrofinable and Bottoms Fractions
Vacuum Fractionation
Large Amounts of Bottoms, plus Solvent Contaminated with the Oil's Volatile Compounds
Reduction of Contaminants with Hydrogen Releasing Same from Oil
Hydrofining
H_2O, H_2S, NH_3, plus Metallic/Carbon Sludge
Purified Base Lube Oil Stock for Further Processing or Blending

Table 45 (Continued). EXAMPLE PROCESS TRAIN

Advantages	Disadvantages
1. Can produce purified base oil stock.	1. Hydrofining requires specialized catalyst.
2. Process concentrates contaminants.	2. Limited to narrow range of waste oil types.
3. Provides a variety of products with one basic flowsheet.	3. Capital & operating costs higher than acid/adsorbent plant.
4. Solvent extraction may be used to break emulsions.	4. Requires sophisticated solvent recovery loop to separate solvent from contaminants.
5. Limited demonstrated performance for waste oils.	5. May require hydrogen-producing support plant.
6. High performance as a finish step (hydrofining) after vacuum distillation for production of a base oil stock.	6. High pressure/high temperature facility.
	7. Complex process with dependence on comprehensive process and quality control.
	8. Significant losses of potential product in residues.
	9. Large amounts of oily wastes (particularly bottoms).
	10. Direct fired heater problems as with stripping.

APPENDIX E

SUMMARY OF COLLECTION SYSTEM RESULTS

(PUP - PIP)

SUMMARY OF COLLECTION SYSTEM RESULTS

PUP - PIP

Sensitivity analyses were run for the collection systems and transport without intermediate storage (PUP) and with intermediate storage (PIP).

They included conditions that could be construed as "Worst" and "Best" plus conditions that reflected "Good" engineering and institutional judgment. Values were given for each of the elements in the total system to reflect the above three conditions and for annual pickup volumes of 18, 19.8, and 22 million gallons per year. These are indicated in the tables preceding the respective PUP and PIP sections of this Appendix.

Table 46. PUP SYSTEM NUMERICAL PARAMETERS

Parameter	Best	Worst	Good	
θ	.25	1.00	.50	Overhead factor
FC_{PUP}	$ 9,100	$ 9,100	$9,000/yr.	Fixed charge
MI_{PUP}	$ 0.10	$ 0.10	$ 0.10/mi.	Cost/mile
Fc_z	1.06	1.4	1.3 (all z)	Circuity factor
$\overline{CAP}_z$		printout		Average storage capacity
M_z		printout		Number of sources
V_{PUP}	2,800 gal.	2,800 gal.	2,800.gal.	Storage capacity of truck
A_z				Area of region
Fc_{pz}	1.06	1.3	1.2 (all z)	Circuity factor from z to plant
γ_t	0.50	0.22	0.36	Utilization factor
Ω	1.00	0.67	0.87	Overflow factor
SL_z	25 mph	10 mph	15 mph	Average speed in z
SR_z	50 mph	40 mph	50 mph	Average speed between z and plant
PR_{PUP}	8,400 gal./hr.	6,000 gal./hr.	7,200 gal./hr.	Pumping rate
w_{sz}	0.08 hr.	0.25 hr.	0.17 hr.	Waiting time - z
W_p	0.05 hr.	0.20 hr.	0.10 hr.	Waiting time - plant
ND	1.0	1.25	1.0	Number of drivers per truck
LD	$5.93/hr	$7.06/hr.	$6.50/hr.	Labor rate of driver
NSW_t	0.0	0.25	0.0	Number of support workers per truck
LSW	$2.96/hr.	$4.15/hr.	$3.55/hr.	Labor rate of support workers
INS_t	$1,000	$1,000	$1,000	Insurance cost

Table 47. PUP SYSTEM - TOTALS OVER ALL REGIONS

PLANT LOCATION: Baltimore

VOLUME - Million Gallons Per Year: 18.0

		Best	Worst	Good
TOTAL NUMBER OF TRUCKS		7.49	40.33	20.76
DISTANCE TRAVELED	(mi/yr)	277,266	277,266	277,266
EQUIPMENT COST	($)	95,966	394,817	216,704
LABOR COST	($/yr)	140,235	598,758	283,790
INSURANCE COST	($/yr)	7,499	40,340	20,767
TOTAL DIRECT COST	($/yr)	243,700	1,033,914	521,261
TOTAL OVERHEAD	($/yr)	12,185	155,087	52,126
TOTAL COST	($/yr)	255,885	1,189,001	573,387
COST/GALLON	($/gal.)	0.0142	0.0661	0.0319

Table 48. PUP SYSTEM - TOTALS OVER ALL REGIONS

PLANT LOCATION: Waldorf

VOLUME - Million Gallons Per Year: 18.0

		Best	Worst	Good
TOTAL NUMBER OF TRUCKS		10.70	52.29	26.29
DISTANCE TRAVELED	(mi/yr)	782,415	782,415	782,415
EQUIPMENT COST	($)	175,634	554,111	317,483
LABOR COST	($/yr)	200,146	776,188	359,272
INSURANCE COST	($/yr)	10,702	52,293	26,290
TOTAL DIRECT COST	($/yr)	385,482	1,382,593	703,045
TOTAL OVERHEAD	($/yr)	19,324	207,389	70,304
TOTAL COST	($/yr)	405,806	1,589,982	773,349
COST/GALLON	($/gal.)	0.0225	0.0883	0.0430

Table 49. PUP SYSTEM - TOTALS OVER ALL REGIONS

PLANT LOCATION: Columbia

VOLUME - Million Gallons Per Year: 18.0

		Best	Worst	Good
TOTAL NUMBER OF TRUCKS		7.92	41.91	21.49
DISTANCE TRAVELED	(mi/yr)	343,813	343,813	343,813
EQUIPMENT COST	($)	106,461	415,802	229,980
LABOR COST	($/yr)	148,127	622,132	293,734
INSURANCE COST	($/yr)	7,921	41,914	21,494
TOTAL DIRECT COST	($/yr)	262,510	1,079,848	545,208
TOTAL OVERHEAD	($/yr)	13,125	161,977	54,521
TOTAL COST	($/yr)	275,635	1,241,825	599,729
COST/GALLON	($/gal.)	0.0153	0.0690	0.0333

Table 50. PUP SYSTEM - TOTALS OVER ALL REGIONS

PLANT LOCATION: Baltimore

VOLUME - Million Gallons Per Year: 19.8

		Best	Worst	Good
TOTAL NUMBER OF TRUCKS		8.21	44.18	22.74
DISTANCE TRAVELED	(mi/yr)	302,223	302,223	302,223
EQUIPMENT COST	($)	104,977	432,302	237,216
LABOR COST	($/yr)	153,623	655,828	310,845
INSURANCE COST	($/yr)	8,215	44,185	22,747
TOTAL DIRECT COST	($/yr)	266,814	1,132,314	570,808
TOTAL OVERHEAD	($/yr)	13,341	169,847	57,081
TOTAL COST	($/yr)	280,155	1,302,162	627,889
COST/GALLON	($/gal.)	0.0141	0.0658	0.0317

Table 51. PUP SYSTEM - TOTALS OVER ALL REGIONS

PLANT LOCATION: Waldorf

VOLUME - Million Gallons Per Year: 19.8

		Best	Worst	Good
TOTAL NUMBER OF TRUCKS		11.73	57.33	28.82
DISTANCE TRAVELED	(mi/yr)	858,066	858,066	858,066
EQUIPMENT COST	($)	192,640	607,582	348,108
LABOR COST	($/yr)	219,546	851,065	393,902
INSURANCE COST	($/yr)	11,740	57,338	28,824
TOTAL DIRECT COST	($/yr)	423,925	1,515,985	770,835
TOTAL OVERHEAD	($/yr)	21,196	227,398	77,083
TOTAL COST	($/yr)	445,121	1,743,383	847,918
COST/GALLON	($/gal.)	0.0225	0.0880	0.0428

Table 52. PUP SYSTEM - TOTALS OVER ALL REGIONS

PLANT LOCATION: Columbia

VOLUME - Million Gallons Per Year: 19.8

		Best	Worst	Good
TOTAL NUMBER OF TRUCKS		8.67	45.91	23.54
DISTANCE TRAVELED	(mi/yr)	375,531	375,531	375,531
EQUIPMENT COST	($)	116,538	455,419	251,841
LABOR COST	($/yr)	162,317	681,577	321,799
INSURANCE COST	($/yr)	8,680	45,919	23,548
TOTAL DIRECT COST	($/yr)	287,535	1,182,915	597,189
TOTAL OVERHEAD	($/yr)	14,377	177,437	59,719
TOTAL COST	($/yr)	301,912	1,360,353	656,907
COST/GALLON	($/gal.)	0.0152	0.0687	0.0332

Table 53. PUP SYSTEM - TOTALS OVER ALL REGIONS

PLANT LOCATION: Baltimore

VOLUME - Million Gallons Per Year: 22.0

		Best	Worst	Good
TOTAL NUMBER OF TRUCKS		9.07	48.78	25.11
DISTANCE TRAVELED	(mi/yr)	332,162	332,162	332,162
EQUIPMENT COST	($)	115,763	477,123	261,745
LABOR COST	($/yr)	169,636	724,053	343,184
INSURANCE COST	($/yr)	9,071	48,781	25,113
TOTAL DIRECT COST	($/yr)	294,470	1,249,957	630,042
TOTAL OVERHEAD	($/yr)	14,723	187,493	63,004
TOTAL COST	($/yr)	309,193	1,437,450	693,046
COST/GALLON	($/gal.)	0.0141	0.0655	0.0316

Table 54. PUP SYSTEM - TOTALS OVER ALL REGIONS

PLANT LOCATION: Waldorf

VOLUME - Million Gallons Per Year: 22.0

		Best	Worst	Good
TOTAL NUMBER OF TRUCKS		12.97	63.36	31.85
DISTANCE TRAVELED	(mi/yr)	948,391	948,391	948,391
EQUIPMENT COST	($)	212,949	671,446	384,684
LABOR COST	($/yr)	242,721	940,500	435,265
INSURANCE COST	($/yr)	12,979	63,363	31,851
TOTAL DIRECT COST	($/yr)	468,649	1,675,309	851,800
TOTAL OVERHEAD	($/yr)	23,432	251,296	85,180
TOTAL COST	($/yr)	492,082	1,926,606	936,980
COST/GALLON	($/gal.)	0.0224	0.0877	0.0427

Table 55. PUP SYSTEM - TOTALS OVER ALL REGIONS

PLANT LOCATION: Columbia

VOLUME - Million Gallons Per Year: 22.0

		Best	Worst	Good
TOTAL NUMBER OF TRUCKS		9.58	50.70	26.00
DISTANCE TRAVELED	(mi/yr)	413,440	413,440	413,440
EQUIPMENT COST	($)	128,581	502,754	277,960
LABOR COST	($/yr)	179,276	752,602	355,330
INSURANCE COST	($/yr)	9,586	50,704	26,002
TOTAL DIRECT COST	($/yr)	317,443	1,306,059	659,291
TOTAL OVERHEAD	($/yr)	15,872	195,909	65,929
TOTAL COST	($/yr)	333,316	1,501,968	725,220
COST/GALLON	($/gal.)	0.0152	0.0684	0.0330

Table 56. PIP SYSTEM NUMERICAL PARAMETERS

	Worst	Good	Best
Capacity Local Vehicle - gal.	2800.	2800.	2800.
Local Vehicle Utilization Factor	0.24	0.24	0.24
Local Vehicle Overflow Factor	0.67	0.87	1.00
Speed in Region - mph	10	15	25
Local Vehicle -			
Pumping Rate gal./hr	6000	7200	8400
Local Source -			
Waiting Time hr	0.50	0.33	0.17
Local Vehicle -			
Fixed Charge $	9100	9100	9100
Cost/mi $/mi	0.10	0.10	0.10
Drivers/Vehicle	1.00	1.00	1.00
Labor Cost of Drivers $	7.06	6.50	5.93
Support Workers/Vehicle	0.25	0.0	0.0
Labor Cost Support Workers $	4.15	3.55	2.96
Insurance $/yr	1000	1000	1000
Local Operation -			
Overhead Factor	0.15	0.10	0.05
IST Site Development Factor	0.05	0.05	0.05
IST Engineering Factor	0.15	0.15	0.15
IST Fee Factor	0.05	0.05	0.05
IST Set Back - ft	8.	8.	8.
IST Parking Lot Factor	0.0019	0.0019	0.0
IST Land Cost $/sq.ft.	0.50	0.25	0.10
IST Constant A-10	0.0	0.0	0.0
IST Constant A-11	0.3920	0.3920	0.3920
IST Constant A-20	14262	14262	14262
IST Constant A-21	0.0511	0.0511	0.0511
IST Operation & Maintenance Factor	0.15	0.10	0.05
IST Life yr.	15.	15.	15.
IST Salvage Value Factor	0.05	0.05	0.05

Table 56 (Continued). PIP SYSTEM NUMERICAL PARAMETERS

	Worst	Good	Best
Long Haul -			
Trailer Capacity - gal.	6000.	6000.	6000.
Trailer Utilization Factor	0.60	0.75	0.95
Trailer Overflow Factor	0.67	0.84	1.00
Annual Charge Trailor $	3900.	3900.	3900.
Cost/Mi. Trailor $/mi.	0.0210	0.0210	0.0210
Support Workers/Trailor	0.30	0.20	0.10
Support Workers Cost $/hr	4.15	3.55	2.96
Tractor Utilization Factor	0.60	0.75	0.95
Tractor Overflow Factor	1.00	1.00	1.00
Speed mph	30.	40.	50.
Annual Charge Tractor $	10920.	10920.	10920.
Cost/Mi. Tractor $/mi.	0.10	0.10	0.10
Cost Tractor Drivers $/hr.	7.06	6.50	5.93
Cost Tractor Support Workers	4.15	3.55	2.96
Support Workers/Tractor	0.25	0.0	0.0
Drivers/Tractor	1.00	1.00	1.00
Overhead	0.15	0.10	0.05
Insurance - Trailor $	430.	430.	430.
Insurance - Tractor $	1200.	1200.	1200.
Waiting Time at Plant hr.	0.20	0.10	0.05
Pumping Rate at Plant gal./hr	10000.	12000.	14000.

Table 57. PIP SYSTEM - TOTALS OVER ALL REGIONS

PLANT LOCATION: Baltimore

VOLUME - Million Gallons Per Year: 18.0

			Best	Worst	Good
LOCAL REGION:	No. Vehicles		6.13	34.74	18.26
	Equipment Cost	($)	63,514	323,871	173,823
	Labor Cost	($/yr)	114,718	591,505	249,481
	Insurance Cost	($/yr)	6,134	34,745	18,256
	Direct Cost	($/yr)	184,368	950,121	441,560
	Total Cost	($/yr)	193,586	1,092,739	485,716
INTERMEDIATE STORAGE:	Investment Cost	($)	95,473	97,325	96,207
	Operation Cost	($/yr)	10,796	20,621	15,643
	Total Capacity	(gal.)	376,949	376,950	376,950
LONG HAUL:	No. Trailors		0.61	2.51	1.20
	No. Tractors		0.23	0.60	0.36
	Equipment Cost	($)	16,239	27,671	19,976
	Labor Cost	($/yr)	12,664	83,984	30,891
	Insurance Cost	($/yr)	535	1,794	947
	Direct Cost	($/yr)	29,438	113,449	41,813
	Total Direct Cost and Overhead	($/yr)	30,910	130,466	45,995
YEARLY DISTANCE TRAVELED:		(miles)	170,938	170,938	170,938
TOTAL COST OF PIP SYSTEM:		($/yr)	235,392	1,243,724	547,353
COST/GALLON:		($/gal.)	0.0131	0.0691	0.0304

Table 58. PIP SYSTEM - TOTALS OVER ALL REGIONS

PLANT LOCATION: Waldorf

VOLUME - Million Gallons Per Year: 18.0

			Best	Worst	Good
LOCAL REGION:	No. Vehicles		6.13	34.74	18.26
	Equipment Cost	($)	63,515	323,871	173,823
	Labor Cost	($/yr)	114,718	591,505	249,481
	Insurance Cost	($/yr)	6,134	34,745	18,256
	Direct Cost	($/yr)	184,368	950,121	441,560
	Total Cost	($/yr)	193,586	1,092,639	485,716
INTERMEDIATE STORAGE:	Investment Cost	($)	95,473	97,325	96,207
	Operation Cost	($/yr)	10,796	20,621	15,643
	Total Capacity	(gal.)	376,950	376,950	376,950
LONG HAUL:	No. Trailors		1.18	4.74	2.27
	No. Tractors		0.79	2.09	1.26
	Equipment Cost	($)	53,206	81,290	62,513
	Labor Cost	($/yr)	42,054	154,150	64,234
	Insurance Cost	($/yr)	1,460	4,551	2,484
	Direct Cost	($/yr)	96,720	239,991	129,231
	Total Direct Cost and Overhead	($/yr)	101,556	275,990	142,154
YEARLY DISTANCE TRAVELED:		(miles)	406,970	406,970	406,970
TOTAL COST OF PIP SYSTEM:		($/yr)	305,938	1,389,248	643,513
COST/GALLON:		($/gal.)	0.0170	0.0772	0.0358

Table 59. PIP SYSTEM - TOTALS OVER ALL REGIONS

PLANT LOCATION: Columbia

VOLUME - Million Gallons Per Year: 18.0

			Best	Worst	Good
LOCAL REGION:	No. Vehicles		6.13	34.74	18.25
	Equipment Cost	($)	63,515	323,871	173,823
	Labor Cost	($/yr)	114,718	591,505	249,481
	Insurance Cost	($/yr)	6,134	34,745	18,256
	Direct Cost	($/yr)	184,368	950,121	441,560
	Total Cost	($/yr)	193,586	1,092,639	485,716
INTERMEDIATE STORAGE:	Investment Cost	($)	95,473	97,325	96,207
	Operation Cost	($/yr)	10,796	20,621	15,643
	Total Capacity	(gal.)	376,950	376,950	376,950
LONG HAUL:	No. Trailors		0.69	2.80	1.34
	No. Tractors		0.30	0.79	0.48
	Equipment Cost	($)	21,114	34,742	25,585
	Labor Cost	($/yr)	16,539	93,236	26,606
	Insurance Cost	($/yr)	657	2,158	1,149
	Direct Cost	($/yr)	38,311	130,136	53,341
	Total Direct Cost and Overhead	($/yr)	40,226	149,656	58,675
YEARLY DISTANCE TRAVELED:		(miles)	202,063	202,063	202,063
TOTAL COST OF PIP SYSTEM:		($/yr)	244,608	1,262,914	560,033
COST/GALLON:		($/gal.)	0.0136	0.0702	0.0311

Table 60. PIP SYSTEM - TOTALS OVER ALL REGIONS

PLANT LOCATION: Baltimore

VOLUME - Million Gallons Per Year: 19.8

			Best	Worst	Good
LOCAL REGION:	No. Vehicles		6.72	38.05	19.99
	Equipment Cost	($)	69,341	354,443	190,154
	Labor Cost	($/yr)	125,614	647,719	273,219
	Insurance Cost	($/yr)	6,717	38,047	19,993
	Direct Cost	($/yr)	201,672	1,040,208	483,366
	Total Cost	($/yr)	211,755	1,196,238	531,703
INTERMEDIATE STORAGE:	Investment Cost	($)	99,669	101,780	100,510
	Operation Cost	($/yr)	11,269	21,552	16,336
	Total Capacity	(gal.)	410,769	410,769	410,769
LONG HAUL:	No. Trailors		0.68	2.76	1.32
	No. Tractors		0.25	0.66	0.39
	Equipment Cost	($)	17,863	30,438	21,973
	Labor Cost	($/yr)	13,930	87,838	22,980
	Insurance Cost	($/yr)	589	1,974	1,041
	Direct Cost	($/yr)	32,382	120,249	45,995
	Total Direct Cost and Overhead	($/yr)	34,001	138,287	50,594
YEARLY DISTANCE TRAVELED:		(miles)	185,575	185,575	185,575
TOTAL COST OF PIP SYSTEM:		($/yr)	257,025	1,356,077	598,633
COST/GALLON:		($/gal.)	0.0130	0.0685	0.0302

Table 61. PIP SYSTEM - TOTALS OVER ALL REGIONS

PLANT LOCATION: Waldorf

VOLUME - Million Gallons Per Year: 19.8

			Best	Worst	Good
LOCAL REGION:	No. Vehicles		6.72	38.05	19.99
	Equipment Cost	($)	69,341	354,443	190,154
	Labor Cost	($/yr)	125,614	647,719	273,219
	Insurance Cost	($/yr)	6,717	38,047	19,993
	Direct Cost	($/yr)	201,672	1,040,208	483,366
	Total Cost	($/yr)	211,755	1,196,238	531,703
INTERMEDIATE STORAGE:	Investment Cost	($)	99,669	101,780	100,510
	Operation Cost	($/yr)	11,269	21,552	16,336
	Total Capacity	(gal.)	410,769	410,769	410,769
LONG HAUL:	No. Trailors		1.30	5.22	2.50
	No. Tractors		0.87	2.30	1.38
	Equipment Cost	($)	58,526	89,419	68,765
	Labor Cost	($/yr)	46,259	165,020	70,657
	Insurance Cost	($/yr)	1,606	5,006	2,733
	Direct Cost	($/yr)	106,392	259,446	142,154
	Total Direct Cost and Overhead	($/yr)	111,712	298,363	156,369
YEARLY DISTANCE TRAVELED:		(miles)	445,210	445,210	445,210
TOTAL COST OF PIP SYSTEM:		($/yr)	334,735	1,516,153	704,408
COST/GALLON:		($/gal.)	0.0169	0.0766	0.0356

Table 62. PIP SYSTEM - TOTALS OVER ALL REGIONS

PLANT LOCATION: Columbia

VOLUME - Million Gallons Per Year: 19.8

			Best	Worst	Good
LOCAL REGION:	No. Vehicles		6.72	38.05	19.99
	Equipment Cost	($)	69,341	354,443	190,154
	Labor Cost	($/yr)	125,614	647,719	273,219
	Insurance Cost	($/yr)	6,717	38,047	19,993
	Direct Cost	($/yr)	201,671	1,040,208	483,366
	Total Cost	($/yr)	211,755	1,196,238	531,703
INTERMEDIATE STORAGE:	Investment Cost	($)	99,699	101,780	100,510
	Operation Cost	($/yr)	11,269	21,552	16,336
	Total Capacity	(gal.)	410,769	410,769	410,769
LONG HAUL:	No. Trailors		0.76	3.08	1.48
	No. Tractors		0.33	0.87	0.52
	Equipment Cost	($)	23,225	38,216	28,144
	Labor Cost	($/yr)	18,193	98,016	29,267
	Insurance Cost	($/yr)	723	2,364	1,264
	Direct Cost	($/yr)	42,142	138,605	58,675
	Total Direct Cost and Overhead	($/yr)	44,249	159,396	64,542
YEARLY DISTANCE TRAVELED:		(miles)	219,813	219,813	219,813
TOTAL COST OF PIP SYSTEM:		($/yr)	267,273	1,377,185	612,581
COST/GALLON:		($/gal.)	0.0135	0.0696	0.0309

Table 63. PIP SYSTEM - TOTALS OVER ALL REGIONS

PLANT LOCATION: Baltimore

VOLUME - Million Gallons Per Year: 22.0

			Best	Worst	Good
LOCAL REGION:	No. Vehicles		7.41	41.97	22.06
	Equipment Cost	($)	76,238	490,777	209,552
	Labor Cost	($/yr)	138,573	714,585	301,460
	Insurance Cost	($/yr)	7,410	41,975	22,060
	Direct Cost	($/yr)	222,221	1,147,336	533,072
	Total Cost	($/yr)	233,332	1,319,435	586,378
INTERMEDIATE STORAGE:	Investment Cost	($)	105,580	107,811	106,470
	Operation Cost	($/yr)	11,937	22,830	17,305
	Total Capacity	(gal.)	452,308	452,308	452,308
LONG HAUL:	No. Trailors		0.75	3.06	1.47
	No. Tractors		0.28	0.73	0.44
	Equipment Cost	($)	19,812	33,759	24,370
	Labor Cost	($/yr)	15,450	92,463	25,487
	Insurance Cost	($/yr)	653	2,189	1,155
	Direct Cost	($/yr)	35,915	128,410	51,012
	Total Direct Cost and Overhead	($/yr)	37,710	147,671	56,113
YEARLY DISTANCE TRAVELED:		(miles)	202,776	202,776	202,776
TOTAL COST OF PIP SYSTEM:		($/yr)	282,980	1,489,937	659,797
COST/GALLON:		($/gal.)	0.0129	0.0678	0.0300

Table 64. PIP SYSTEM - TOTALS OVER ALL REGIONS

PLANT LOCATION: Waldorf

VOLUME - Million Gallons Per Year: 22.0

			Best	Worst	Good
LOCAL REGION:	No. Vehicles		7.41	41.97	22.06
	Equipment Cost	($)	76,238	390,777	209,552
	Labor Cost	($/yr)	138,573	714,585	301,460
	Insurance Cost	($/yr)	7,410	41,975	33,060
	Direct Cost	($/yr)	222,221	1,147,336	533,060
	Total Cost	($/yr)	233,332	1,319,435	586,379
INTERMEDIATE STORAGE:	Investment Cost	($)	105,580	107,811	106,470
	Operation Cost	($/yr)	11,937	22,830	17,305
	Total Capacity	(gal.)	452,308	452,308	452,308
LONG HAUL:	No. Trailors		1.44	5.79	2.77
	No. Tractors		0.97	2.55	1.53
	Equipment Cost	($)	64,911	99,174	76,266
	Labor Cost	($/yr)	51,306	178,065	78,365
	Insurance Cost	($/yr)	1,781	5,552	3,031
	Direct Cost	($/yr)	117,998	282,792	157,662
	Total Direct Cost and Overhead	($/yr)	123,898	325,210	173,428
YEARLY DISTANCE TRAVELED:		(miles)	490,736	490,736	490,736
TOTAL COST OF PIP SYSTEM:		($/yr)	369,168	1,667,476	777,112
COST/GALLON:		($/gal.)	0.0168	0.0759	0.0354

Table 65. PIP SYSTEM - TOTALS OVER ALL REGIONS

PLANT LOCATION: Columbia

VOLUME - Million Gallons Per Year: 22.0

			Best	Worst	Good
LOCAL REGION:	No. Vehicles		7.41	41.97	22.06
	Equipment Cost	($)	76,238	390,777	209,552
	Labor Cost	($/yr)	138,573	714,585	201,460
	Insurance Cost	($/yr)	7,410	41,975	22,060
	Direct Cost	($/yr)	222,221	1,146,336	533,072
	Total Cost	($/yr)	233,332	1,319,435	586,379
INTERMEDIATE STORAGE:	Investment Cost	($)	105,580	106,811	106,470
	Operation Cost	($/yr)	11,937	22,830	17,305
	Total Capacity	(gal.)	452,308	452,308	452,308
LONG HAUL:	No. Trailors		0.84	3.42	1.64
	No. Tractors		0.37	0.97	0.58
	Equipment Cost	($)	25,759	42,385	31,214
	Labor Cost	($/yr)	20,178	103,751	32,460
	Insurance Cost	($/yr)	802	2,632	1,402
	Direct Cost	($/yr)	46,739	148,768	65,076
	Total Direct Cost and Overhead	($/yr)	49,076	171,083	71,583
YEARLY DISTANCE TRAVELED:		(miles)	240,749	240,749	240,749
TOTAL COST OF PIP SYSTEM:		($/yr)	294,345	1,513,348	675,267
COST/GALLON:		($/gal.)	0.0134	0.0689	0.0307

APPENDIX F

PIPE LINE AND BARGE TRANSPORT OF WASTE OILS

PIPE LINE AND BARGE TRANSPORT OF WASTE OILS

Pipe line transport is a technically viable alternative means of transporting waste oils from the intermediate storage sites to the central processing plant. However, the transport of toxic and hazardous materials via pipe line along with waste oil may present hazards both in cross-contamination during segregation of the basic waste oil categories and excessive corrosion. For example, toxic wastes could be mixed sufficiently with crankcase oil to cause contamination of a large fraction of the crankcase oil being moved in the same line.

An analysis may be pursued after making certain assumptions. If it is assumed that the problem of cross-contamination is not a serious one, and that the following conditions prevail:

1) All oily wastes are piped in same line,

2) Transport is from an intermediate site to plant,

3) Average annual system flow is 24,000,000 gallons of all waste fluids,

4) Average length of pipeline is 50 miles,

5) Flow takes place 24 hours/day, 330 days/year,

6) Five intermediate storage sites are used with separate lines from each to the plant, and

7) Optimum design pipe diameter is approximately 3" for peak use in later years.

Instantaneous flow rate is $\frac{24{,}000{,}000}{5} \; \frac{365}{330} = 5{,}300{,}000$ gallons/year/line (610 GPH).

3" pipe --- 3 feet of right of way (25¢/sq. ft.)

Backfill, tamp & trenching * - - - -	$1.75/ft.
Pipe & fitting * - - - - - - - - - - -	6.00/ft. installed
Right of way - - - - - - - - - - - - -	0.75/ft.
	$8.50/ft.

Total cost less pumping station = 50 miles x 5,280 ft/mi. x $8.50

= $2,230,000

Pumping stations @ 25% ** = 557,500

$2,787,500

Annual D & I (6% @ 20 years) = .087 x 2,787,500 = $244,000/yr.

Operating expenses = $2,600/mi. x 250 mi.

= $650,000/yr.

TOTAL ANNUAL COST - - - - - - $894,000

Table 66 shows the variation in cost with volumetric rate in the pipeline.

Table 66. UNIT COST OF PIPELINE WASTE OILS ***

Gals/Day	Annual Volume (Gal/Year)	Total Pipeline Transport Costs (¢/Gal)
55,000	1,820,000	49.6
10,000	3,600,000	24.8
15,000	5,460,000	16.4
20,000	7,280,000	12.3
25,000	9,100,000	9.85
40,000	14,400,000	6.23
60,000	21,600,000	4.14
70,000	25,200,000	3.55

---

* R. S. Means, "Building Construction Cost Data".

** Based on analysis of Sohio Pipe Line Co., Annual Report ending 12/31/72, I.C.C. #009395

*** Annual charges assumed to remain approximately constant at $894,000 per year.

The cost factors of Table 66 may be compared with the cost of using long-haul trucks (6,000-gallon capacity) to accomplish the same ends as calculated using the PIP System Model. The cost of using long-haul trucks does not exceed 1.5¢ per gallon even using the most pessimistic combinations of cost parameters. Thus the use of pipelines for the transport of waste oils does not appear economical aside from other considerations.

Barging is a viable transport alternative only in the case of oils transported between the Eastern Shore region of Maryland and a reprocessing plant located in the vicinity of a usable port, e.g., Baltimore. The cost of barging should then be compared with that associated with using long-haul trucks (6,000-gallon capacity) to transport oil between the Eastern Shore and a plant located in, say, the Baltimore Port region. The PIP system long-haul trucking costs for this case range from about 1¢ per gallon under the best estimate combination of cost parameters to over 4¢ per gallon using the most pessimistic combinations of cost parameters. These costs compare with the barging costs of less than 1/2¢ per gallon, excluding demurrage, quoted in the preceding paragraphs.

Barging is, therefore, an economically attractive alternative to long-haul trucking from the Eastern Shore. However, the standard barge sizes are 840,000 gallons and 1,750,000 gallons. The annual waste oil generation rate of the Eastern Shore is estimated to fall between these two values. Therefore, unless the higher per gallon cost associated with practical barge loads is to be encountered, about one barge trip per year from the Eastern Shore will suffice for the waste oil recovery. This will involve larger IST tanks at an Eastern Shore site and increased storage capacity at the reprocessing plant to account for these surge deliveries. The added cost associated with the increased tankage is probably not so much a consideration as the operational impact of "slugging" the system at widely separated time intervals.

Table 67. BARGE COSTS

Assumptions:

No split load - composition "uniform"

Minimum pumping rate = 105,000 gal/hr

Standard barge sizes used for this analysis:

840,000 gals. or 1,750,000 gals.

Rates:

Washington to Baltimore - - - - - 25¢/bbl = 0.6¢/gal.

Crisfield, Md. to Baltimore - - - 19¢/bbl = 0.45¢/gal.

Cambridge, Md. to Baltimore - - - 15¢/bbl = 0.36¢/gal.

Demurrage due to lost time at terminal is $70.000/hour for 20,000 bbl barge.

Split Discharge Rates, e.g., Washington 10,000 bbl's, pickup, Crisfield 6,000 bbl's, Cambridge 6,000 bbl's would involve costs which lie between the rates shown above.

Barge pump discharge pressure maximum = 125 psi.

Barge size = 240' x 50' - - - - Tug = 90' long

There is a good probability that the load can be picked up within 10 days notice. Terminal cost is the function of storage volume. However, minimum is 20,000 bbl's with the added uncertainty of fill rate and wait time.

APPENDIX G

DETERMINING THE SIZE OF AN INTERMEDIATE STORAGE TANK (IST)

DETERMINING THE SIZE OF AN INTERMEDIATE STORAGE TANK (IST)

Theoretically, the intermediate storage tank (IST) in the PIP system should be of the same capacity as the long-haul vehicle (IP). Any additional capacity is unused if the system works perfectly and therefore represents an unjustified expenditure. In practice, however, this will not hold exactly. Since the calculated delivery frequency of the local collection vehicles (PUP) to the IST is an average frequency, the delivery rate is bound to vary about the mean, and when the rate becomes higher than the average by a significant amount, an IST tank of the exact efficient size could be in an overflow mode. Also, the IP system picking up the waste from the IST and delivering it to the reprocessing plant may fall behind schedule for any of a number of reasons. Finally, in densely populated regions, where the rates of PUP deliveries and IP pickups are high, the mere traffic density may keep the system from operating at designed efficiency. Therefore, it seems prudent to purposely design some excess capacity into the tanks.

Even though the PUP's are scheduled in their deliveries, their arrival rate will undergo variations which will appear random, particularly if observed over short periods of time. It has been established in a number of situations that this sort of phenomenon follows the Poisson distribution rather well (Refs.: Student, Rutherford and Edie Geiger). The frequency of PUP deliveries at an IST in region z is:

$$R_{PUP_z} = \frac{X'z}{52\ V_{PUP}} \text{ arrivals/week}$$

The rate of PUP deliveries in relation to IP pickups is:

$$r = \frac{V_{IP}}{V_{PUP}}$$

Then the mean number of PUP deliveries in the interval between IP pickups is r, and the probability that k PUP deliveries will occur within this interval is:

$$P(k) = \frac{e^{-r}(r)^k}{k!}$$

If a one-week excess capacity is accorded each IST tank, the probability that the waste arriving during the interval

$$\frac{V_{IP}52}{X'z}$$

weeks, will equal or exceed the one-week reserve capacity is:

$$p(k \geq R_{PUP} + r) = \sum_{k=R_{PUP} + r}^{\infty} \left(\frac{e^{-r}}{k!}\right)(r)^k$$

It would be desirable to keep this probability at or below 10 percent. At the ratio of $V_{IP}/V_{PUP} = 2$, the following probabilities may be calculated:

Average Number of PUP Arrivals at IST per week	Total Annual Waste Generation Rate in Region z	IST Capacity	Weeks of Excess Capacity	Probability that IST Capacity Will Be Equaled or Exceeded
1	145,600	8,400	1	.3233
1	145,600	11,200	2	.1429
1	145,600	14,000	3	.0527
2	291,200	11,200	1	.1429
2	291,200	16,800	2	.0166
3	436,800	14,000	1	.0527
4	582,400	16,800	1	.0166

It is clear from the above that more than one week's excess capacity is required to maintain the probability of an overflow at less than 10 percent in the case of regions that have low generation rates of waste oil. Also, in any region, the probability of overflow can be maintained at a low level by providing additional IST capacity.

A suggested rule for selecting IST tank size, which maintains the probability of an overflow below 10 percent and does not result in excessive unused tank capacity is:

V_{IST}	x_z
12,000 gal.	$<$ 145,000 gal./yr.
15,000 gal.	$=$ 145,000 to 440,000 gal./yr.
$6{,}000 + \frac{x_z}{52}$	$>$ 440,000 gal./yr.

It may be noted from the IST cost function that there is a break in tank cost such that there is a rapid drop in the cost per unit volume for tanks exceeding 50,000 gallons. However, it may be seen from the above discussion that tanks of larger than 50,000-gallon capacity do not appear to be necessary.

APPENDIX H

SELECTION OF DISTRIBUTION REGIONS

- QUESTIONNAIRES -

SELECTION OF DISTRIBUTION REGIONS

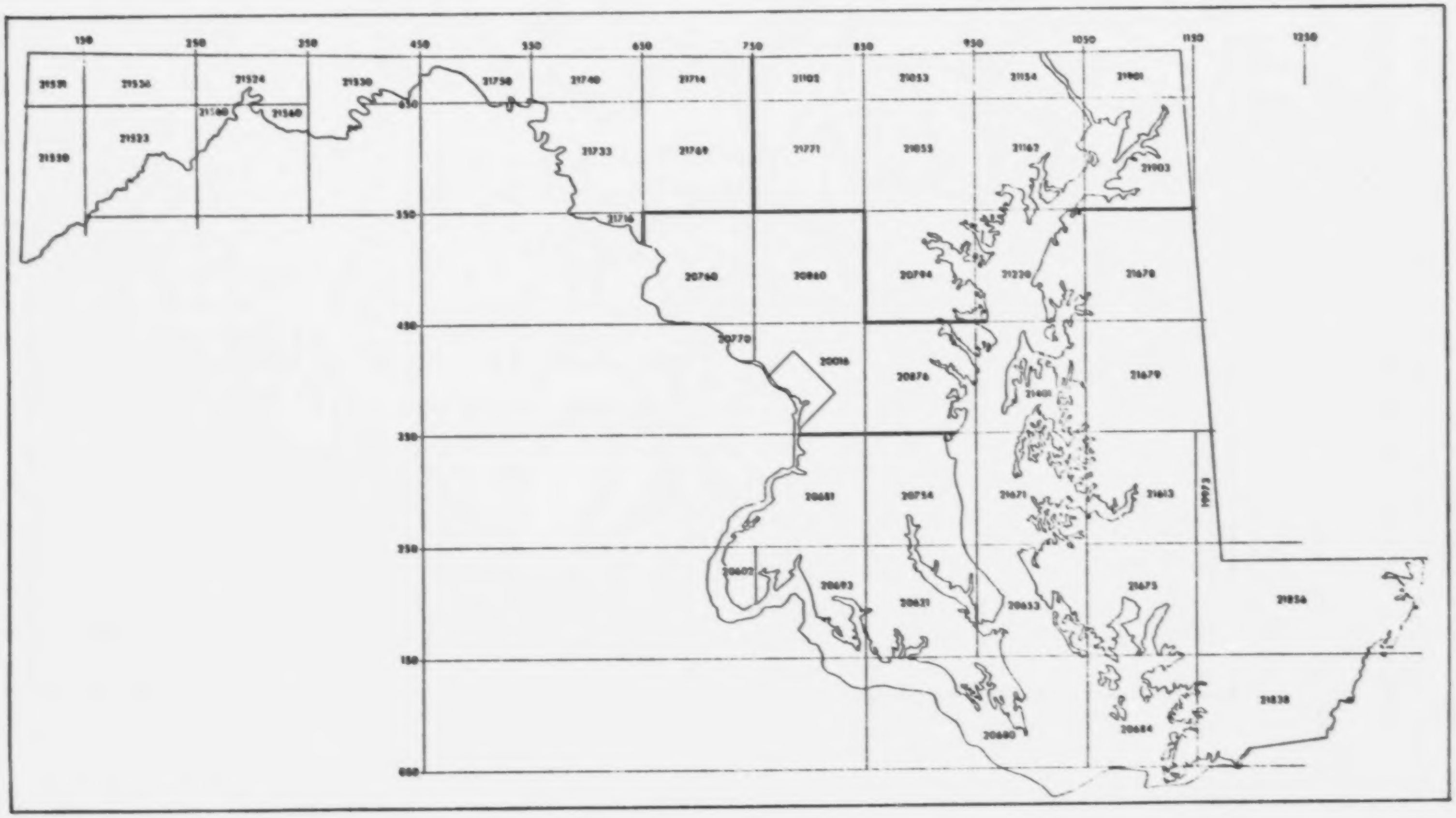
- QUESTIONNAIRES -

A problem encountered in conducting and evaluating the survey was the establishment of a practical yet precise method of geographically locating the waste oil generators. Location by counties appeared to be too imprecise; location by cities lacked homogenity; while location according to such things as census tracts was too difficult to handle in a practical sense. Consequently, the Postal Service zip code was chosen as the basic geographical location device for the survey. Zip codes have the double advantage of being easily obtainable and commonly understood, and of being relatively precise indicators of geographical location. Moreover, zip codes offer finer locational differentiation in densely populated areas than they do in more sparsely populated areas which was desirable in this case. Each of the more than 700 five-digit zip codes were located to the nearest 10,000 geet by means of the Coast and Geodetic Survey Northeast Quadrant Grid System, and stored in a computer. Following this, each recipient of a questionnaire could be located according to his zip code in terms of a north and south grid system, and such things as straight line distance connecting two zip codes was easily calculated.

As the study proceeded, it was found that location by five-digit zip codes resulted in an overly-refined and cumbersome degree of locational accuracy for most of the study's needs. Therefore, all of the zip codes within squares 20,000 feet on a side were combined into a so-called Master Zip Code. The Master Zip Code identifying a Master Zip Code Region was simply the five-digit zip code of the center of population mass within that region, or, in some cases, the geographical center of the 20,000 foot square. These Master Zip Codes and their associated Master Zip Code Regions are displayed on the map shown in Figure 7. The Master Zip Codes and their associated Master Zip Regions form the basic locational index used throughout the MES Waste Oil Survey, and are given in Appendix A.

Even the Master Zip Regions were found to be overly definitive for purposes of the waste oil collection and distribution models, in that the Master Zip Regions produced solutions requiring unrealistically small fractions of trucks and other non-divisible commodities to service an individual Master Zip Code Region. This problem was alleviated by combining several Master Zip Code Regions into one of five Collection and Distribution Regions. The geographical extent of the five Collection and Distribution Regions and the included Master Zip Code Regions are shown in Figure 2 (page 21).

Figure 7. MASTER ZIP CODE REGIONS BASED ON COAST AND GEODETIC SURVEY 100,000 FOOT GRID-STATE OF MARYLAND


150
250
350
450
550
650
750
850
950
1050
1150
1250
650
550
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350
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150
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21536
21524
21530
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21714
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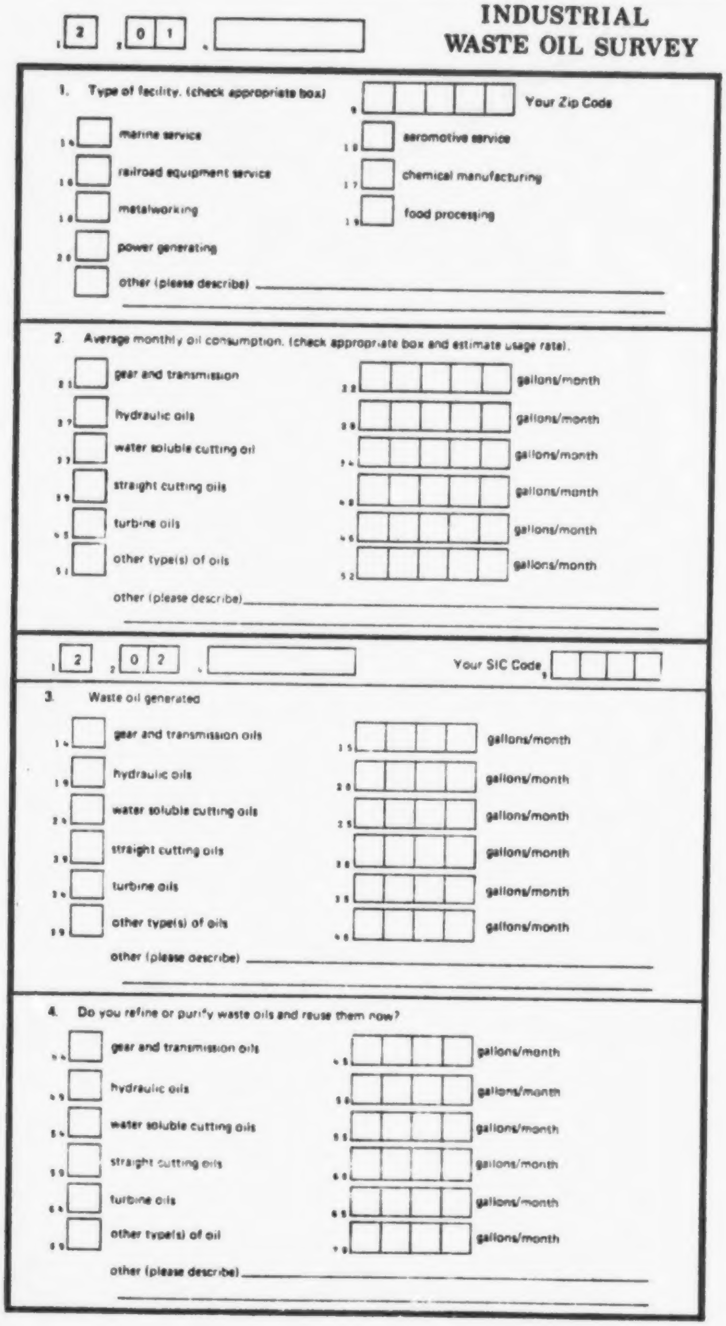
21903
21716
20760
20860
20794
21220
21678
20770
20016
20876
21601
21679
20681
20754
21671
21613
19973
20602
20693
20621
20653
21675
21856
20680
20684
21838

Figure 8. INDUSTRIAL WASTE OIL SURVEY QUESTIONNAIRE



1 2 2 0 1 4 ☐

INDUSTRIAL WASTE OIL SURVEY

1. Type of facility. (check appropriate box)

9 ☐☐☐☐☐ Your Zip Code

14 ☐ marine service

15 ☐ aeromotive service

16 ☐ railroad equipment service

17 ☐ chemical manufacturing

18 ☐ metalworking

19 ☐ food processing

20 ☐ power generating

☐ other (please describe) ____________________

2. Average monthly oil consumption. (check appropriate box and estimate usage rate).

21 ☐ gear and transmission 22 ☐☐☐☐☐ gallons/month

27 ☐ hydraulic oils 28 ☐☐☐☐☐ gallons/month

33 ☐ water soluble cutting oil 34 ☐☐☐☐☐ gallons/month

39 ☐ straight cutting oils 40 ☐☐☐☐☐ gallons/month

45 ☐ turbine oils 46 ☐☐☐☐☐ gallons/month

51 ☐ other type(s) of oils 52 ☐☐☐☐☐ gallons/month

other (please describe) ____________________

1 2 2 0 2 4 ☐ Your SIC Code 9 ☐☐☐☐

3. Waste oil generated

14 ☐ gear and transmission oils 15 ☐☐☐☐ gallons/month

19 ☐ hydraulic oils 20 ☐☐☐☐ gallons/month

24 ☐ water soluble cutting oils 25 ☐☐☐☐ gallons/month

29 ☐ straight cutting oils 30 ☐☐☐☐ gallons/month

34 ☐ turbine oils 35 ☐☐☐☐ gallons/month

39 ☐ other type(s) of oils 40 ☐☐☐☐ gallons/month

other (please describe) ____________________

4. Do you refine or purify waste oils and reuse them now?

44 ☐ gear and transmission oils 45 ☐☐☐☐ gallons/month

49 ☐ hydraulic oils 50 ☐☐☐☐ gallons/month

54 ☐ water soluble cutting oils 55 ☐☐☐☐ gallons/month

59 ☐ straight cutting oils 60 ☐☐☐☐ gallons/month

64 ☐ turbine oils 65 ☐☐☐☐ gallons/month

69 ☐ other type(s) of oil 70 ☐☐☐☐ gallons/month

other (please describe) ____________________

Figure 8 (Continued). INDUSTRIAL WASTE OIL SURVEY QUESTIONNAIRE

1 [2] 2 [Q][3] 4 [ ]

5. How are waste oils not being purified and reused presently being disposed of?

14 ☐ picked up by collector

15 ☐☐☐☐ gallons/pickup

19 ☐☐ pickups/year

21 ☐ burned 22 ☐☐☐☐ gallons/month

6. Do you have holding (storage) tank facilities for waste oil?

26 ☐ yes 27 ☐ no 28 ☐☐☐☐ gallon capacity

If yes, please describe ___

7. Do you segregate waste oils by type?

32 ☐ yes 33 ☐ no

If yes, please describe ___

8. Do you purchase reclaimed or re-refined oil?

34 ☐ yes 35 ☐ no If yes, 36 ☐☐☐☐ gallons/month

Please describe use ___

1 [2] 2 [Q][4] 4 [ ]

9. If waste oils are picked up by a collector, please give name and address of collector.

___

What is cost of pickup? ___ (cents/gallon)

If collector pays you, how much is paid? ___ (cents/gallon)

10. Are your current arrangements for storing, handling or disposing of waste oil satisfactory? If not, what improvements would you like to see made?

___

11. Any additional comments you might have are invited.

___

Upon completion, please forward in the enclosed envelope to:

ENVIRONMENTAL QUALITY SYSTEMS, INC.
6110 Executive Blvd. Suite 750
Rockville, Maryland 20852

Figure 9. WASTE OIL SURVEY QUESTIONNAIRE

1   0 1   3 ☐ 8

WASTE OIL SURVEY

1. Type of facility.   Your Zip Code 9 ☐☐☐☐☐ 13

14 ☐ gasoline service station   15 ☐ auto dealer

16 ☐ fleet service/repair   17 ☐ auto repair

18 ☐ gasoline truck service   19 ☐ diesel truck service

20 ☐ diesel bus service   21 ☐ propane bus service

22 ☐ non-highway vehicle or construction equipment service

23 ☐ other, (please describe) ____________________

2. Approximate number of oil changes performed per month 24 ☐☐☐☐ 27

3. Approximate average volume of oils sold per month (includes transmission oil, hydraulic oil, etc).

28 ☐☐☐☐☐ 32 total gallons/month

33 ☐☐☐ 35 percentage of above resulting from oil changes

4. How much waste oil do you accumulate per month on the average

36 ☐☐☐☐☐ 40 gallons/month

5. How is waste oil disposed of at present? (please check appropriate boxes)

41 ☐ picked up by collector

42 ☐☐☐☐ 45 gallons/pickup

46 ☐☐ 47 pickups/year

48 ☐ burned   49 ☐☐☐☐ 52 gallons/month

53 ☐ other (please describe) ____________________

6. Do you have holding (storage) tank facilities for waste oil?

54 ☐ yes   55 ☐ no   56 ☐☐☐☐ 59 gallon capacity

7. If your waste oil is picked up by a collector, please give name and address of collector ____________________

Cost of pickup (cents/gallon) ____________________

If collector pays you, please describe payment (cents/gallon) ____________________

8. Are your current arrangements for storing, handling, or disposing of waste oil satisfactory? If not, what improvements would you like made?

____

9. Any additional comments you might have are invited

____

Upon completion, please forward in the enclosed envelope to

ENVIRONMENTAL QUALITY SYSTEMS, INC.
6110 Executive Blvd. Suite 750
Rockville, Maryland 20852

APPENDIX I

CRANKCASE AND INDUSTRIAL WASTE OIL SURVEY

The responses to the automotive waste oil survey were tabulated for each of the Master Zip Code Regions. An example of the tabulations of the response received from one Master Zip Code Region (Master Zip Code 20760 - Gaithersburg) is shown in Table 68. It may be noted that 70 Survey questionnaires were sent to retailers of gasoline in this Master Zip Code Region, and 32 questionnaires were returned, for a return percentage of 45.7 percent.

Down the left side of Table 68 are listed the quantitative questions contained in the questionnaire. Reading to the right, on a line with each question, are tabulations of the answers to each question. First appears the sample low. This is the lowest value reported in any responses to the question. Following the sample low is the sample high, the highest value reported in any response to that particular question. The sample total follows to the right and is simply the total of all responses to the question. The number of replies is the number of replies received to that question. Note that the number of replies to any one question may differ from the number of whole questionnaires returned. The sample average is the sample total divided by the number of replies. The sample standard deviation falls under the next column heading,"Sample Std. Dev." and is a measure of the variation among the replies received to that question.

The estimated population total is a statistical estimate of what the sample total would have been had every questionnaire recipient in the Master Zip Code Region responded to that question. The estimated population total is calculated by multiplying the sample average by the number of surveys sent within the Master Zip Code Region. As is the case with all of the estimates of population characteristics, this assumes that the replies of that portion of the population that did respond to the questionnaire are typical of those that the non-responding portion would have made had they responded.

The right most column on Table 68 shows the estimated standard deviation of the estimated population total "Std. Dev. of Est. Pop. Total". This is an estimate of the precision of the estimated population total. The difference between this statistic and the sample standard deviation is worth noting. Whereas the sample standard deviation is a measure of the variations experienced in the replies received, the estimated standard deviation of the estimated population total is a measure of accuracy of another statistical estimate - specifically the estimated population total. If the proportion of replies is small and a great deal of variation is experienced in those few replies that are received, the estimated population total is likely to be off its true value, and the estimated standard deviation of the estimated population total will be large. Conversely, if a high proportion of replies is received to the question of interest and little variation is experienced in those replies, the estimated population total is likely to be very accurate, and the estimated standard deviation of the estimated population total will be small.

Some of the line descriptions on the left side of Table 68 do not correspond to specific questions of the questionnaire but rather are derived from combinations or manipulations of the responses. The first such line description, entitled "Blowby and Leakage Loss (34%)", is the value for consumption indicated by A. D. Little in a study prepared for the State of Massachusetts. This value was used to compare with the values obtained by the Maryland Survey which showed much higher rates of consumption. The Maryland value is also substantially different than the value for consumption of 50 percent of the combination of automotive and industrial lubricants given in the American Petroleum Institute study, "Final Report of the Task Force on Used Oil Disposal".

Following blowby is a line description entitled "Total Recoverable as Waste (66%)". These two lines, therefore, are the result of multiplying the answers to Question Three of the survey by 0.34 and 0.66, respectively. The answers received in Question Four of the survey, "How much waste oil do you accumulate per month on the average?", are generally much less than 66 percent of the quantities of oil sold. In the example shown in Table 68 and in Table 69, "Automotive Waste Oil Survey" results, the extrapolated "Actual Waste Oil Accumulated" is only 34 percent of the oil sold. This apparent discrepancy can be interpreted in a number of different ways, either: 1) more than 34 percent of the automotive crankcase oil is lost due to blowby and leakage (some independent studies show this to be the case); 2) the quantities of oils sold are overstated by the respondees to the survey; 3) the amount of waste oil accumulated by the respondees is understated; or 4) some combination of 1), 2), and 3).

Though it cannot be stated as a conclusion, it is felt that, for the above reasons the volumes of automotive waste oil that can be affected will probably be greater than the volumes extrapolated from the data recovered in the survey.

Following the line description for Question Six ("Do you have holding [storage] tank facilities for waste oil?") of the survey, are three lines showing information that is derived from answers to Questions Two through Six of the questionnaire. The first of these lines is entitled, "Ave. Max. Pickup Freq-Pickups/Yr". This statistic is calculated by dividing 12 times the reported amount of waste oil accumulated per month by the reported waste oil storage capacity. This provides an indication of the number of times waste must be collected from a source over the course of a year and is an important consideration in structuring the collection network. The next line description, entitled, "Ratio of waste oil accum to oil sold", is the ratio of the answers to Question Four ("How much waste oil do you accumulate per month on the average?") and Question Two ("Approximate number of oil changes performed per month?"). The line entitled, "No. of times oil changes x 1 gal. = gal. accum.", is the number of times the assumption that each oil change produces one gallon of waste crankcase oil would be consistent with information reported on the survey questionnaires. In the example of Table 68, this is seen to be the case in 5 percent of the responses.

Tables 69 and 70 compare exactly with Table 68 except that Tables 69 and 70 tabulate the overall, State-wide answers to the questions contained in the survey of automotive waste oil. Here it may be noted that the State-wide response to this questionnaire was 41 percent or 1,675 questionnaires returned out of the 4,077 sent. The estimated total amount of waste oil accumulated per month by gasoline retailers is 459,640 gallons, which equates to 5,515,680 gallons per year.

Questions Seven, Eight, and Nine of the automotive waste oil questionnaire were not posed in such a manner that their answers followed a rigid format. Accordingly, their answers were not amenable to computer processing. These qualitative and variable form answers were read and analyzed by members of the study team and the results were used to provide background.

INDUSTRIAL OIL SURVEY

An example of the survey results for one SIC code (355 - Special Industry Machinery Manufacturing) within one Master Zip Code Region (21055 --- Pikesville) is shown as Table 71. The description lines for the Industrial Oil Survey results are self-explanatory or the same as for the crankcase survey and the columnar headings are the same as those used in presenting the results of the crankcase oil survey.

Table 72 is an example of the results of the Industrial Oil Survey results for the Pikesville Master Zip Code Region, summed across all SIC codes. It may be noted that sample totals, averages, etc., are not shown in Table 72. Such statistics tend to lose their meaning after stratified combination has taken place.

Table 68. AUTOMOTIVE WASTE OIL SUMMARY

(05/03/73)

COORDINATES 0700 0500 NO. SURVEYS SENT 70 NO. SURVEYS RETURNED 32 PERCENT RETURN 45.71%

MASTER ZIP CODE: 20760 GAITHERSBURG

	SAMPLE LOW	SAMPLE HIGH	SAMPLE TOTAL	NO. REPLIES	SAMPLE AVE	SAMPLE STD DEV	EST POP TOTAL	STD DEV OF EST POP TOTAL
OIL CHANGES/MO	20	250	1643	28	59	374	4106	3836
GAL OIL SOLD/MO (ORIG STOCK USAGE)	40	1000	5657	27	209	193	14665	2048
BLOWBY AND LEAKAGE LOSS (34%)			1925				5000	
TOTAL RECOVERABLE AS WASTE (66%)			3732				9665	
ACTUAL GAL WASTE OIL ACCUM/MO	15	300	2602	26	100	90	7004	976
GAL WASTE OIL/MO NOT REPORTED			905				2087	
GAL WASTE OIL PICKED UP/MO	4	240	904	17	53	82	3721	1212
GAL WASTE OIL BURNED/MO	150	150	105	28	5	28	374	290
GAL DISPOSED OF BY OTHER MEANS/MO	34	300	1548		41		2908	
STORAGE CAPACITY - GAL	7	1000	13407	27	496	380	34758	4017
AVE MAX PICKUP FREQ - PICKUPS/YR	1	8	52	17	3	2	213	31
RATIO OF WASTE OIL ACCUM TO OIL SOLD		2	.45		.47		.47	
NO. OF TIMES OIL CHNGS x 1 GAL = GAL ACCUM	1 OUT OF 20 TIMES FOR 5.00%							

Table 69. AUTOMOTIVE WASTE OIL SUMMARY

NO. QUESTIONNAIRES SENT 4077 NO. QUESTIONNAIRES RETURNED 1675 PERCENT RETURN 41%

	SAMPLE LOW	SAMPLE HIGH	SAMPLE TOTAL	NO. REPLIES	SAMPLE AVE	SAMPLE STD DEV	EST POP TOTAL	STD DEV OF EST POP TOTAL
OIL CHANGES/MO	1	1,500	66,022	1,429	47.6	77	194,000	6,730
GAL OIL SOLD/MO (ORIG STOCK USAGE)	1	50,000	458,788	1,393	329	2,284	1,342,000	202,000
BLOWBY AND LEAKAGE LOSS (34%)			156,000				456,000	
TOTAL RECOVERABLE AS WASTE (66%)			302,786				886,000	
ACTUAL GAL WASTE OIL ACCUM/MO	1	20,000	153,327	1,360	113	598	460,000	54,000
GAL WASTE OIL/MO NOT REPORTED			131,121				373,000	
GAL WASTE OIL PICKED UP/MO	.25	2,600	64,583	935	69	169	282,000	19,800
GAL WASTE OIL BURNED/MO	10	800	12,990	1,407	9	53	37,600	4,600
GAL DISPOSED OF BY OTHER MEANS/MO	.8	20,000	75,753		34		140,400	
STORAGE CAPACITY - GAL	5	10,000	570,147	1,351	422	536	1,720,000	48,600
AVE MAX PICKUP FREQ - PICKUPS/YR	1	205	4,173	876	4.8	9.8	10,000	1,200
RATIO OF WASTE OIL ACCUM TO OIL SOLD	.01	9	.33		.34		.34	
NO. OF TIMES OIL CHNGS x 1 GAL = GAL ACCUM	182 OUT OF 1001 TIMES FOR ~18%							

Table 70. WASTE OIL SURVEY RESPONSE FREQUENCY

NO. QUESTIONNAIRES SENT 4077 NO. QUESTIONNAIRES RETURNED 1675 PERCENT RETURN 41%

	GAS STAT	AUTO DEALER	FLT SVC	AUTO REP	GAS/TRUCK	DESL/TRK	DESL/BUS	PROPANE	OFF HIWAY	OTHER
GAS SERVICE STATION	1323/2646	19/38	10/20	130/260	6/12	8/16	4/8	4/8	4/8	27/54
AUTO DEALER	19/38	48/96	3/6	17/34	3/6	4/8	3/6	3/6	3/6	2/4
FLEET SERVICE/REPAIR	10/20	3/6	18/36	6/12	4/8	4/8	3/6	2/4	3/6	3/6
AUTO REPAIR	130/260	17/34	6/12	165/330	4/8	6/12	3/6	3/6	4/8	3/6
GAS TRUCK SERVICE	6/12	3/6	4/8	4/8	9/18	5/10	4/8	3/6	4/8	2/4
DIESEL TRUCK SERVICE	8/16	4/8	4/8	6/12	5/10	12/24	4/8	3/6	3/6	2/4
DIESEL BUS SERVICE	4/8	3/6	3/6	3/6	4/8	4/8	4/8	3/6	3/6	2/4
PROPANE BUS SERVICE	4/8	3/6	2/4	3/6	3/6	3/6	3/6	4/8	3/6	2/4
NON-HIGHWAY/CONST.	4/8	3/6	3/6	4/8	4/8	3/6	3/6	3/6	10/20	2/4
OTHER	27/54	2/4	3/6	3/6	2/4	2/4	2/4	2/4	2/4	267/534
TOTAL BY CATEGORY	1535/3070	0105/0210	0056/0112	0341/0682	0044/0088	0051/0102	0033/0066	0030/0060	0039/0078	0312/0624

XXXX/XXXX = NO. REPLIES / ESTIMATED POPULATION

Table 71. INDUSTRIAL WASTE OIL SUMMARY

COORDINATES 0900 0600 NO. SURVEYS SENT 4 NO. SURVEYS RETURNED 1 PERCENT RETURN 25.00%

	SAMPLE LOW	SAMPLE HIGH	SAMPLE TOTAL	NO. REPLIES	SAMPLE AVE	EST POP TOTAL
GAL OIL CONSUMED/MO						
GEAR AND TRANS	30	30	30	1	30	120
HYDRAULIC OILS	55	55	55	1	55	220
WATER SOL CUTTING	74	74	74	1	74	296
ST CUTTING OIL	36	36	36	1	36	144
TURBINE OIL						
MOTOR OIL						
OTHER	42	42	42	1	42	168
TOTAL	237	237	237	1	237	948
GAL WASTE OIL GEN/MO						
GEAR AND TRANS	10	10	10	1	10	40
HYDRAULIC OILS	10	10	10	1	10	40
WATER SOL CUTTING	55	55	55	1	55	220
ST CUTTING OIL	10	10	10	1	10	40
TURBINE OIL						
MOTOR OIL						
OTHER	10	10	10	1	10	40
TOTAL	95	95	95	1	95	380
GAL WASTE REUSED/MO						
GEAR AND TRANS						
HYDRAULIC OILS						
WATER SOL CUTTING						
ST CUTTING OIL						
TURBINE OIL						
MOTOR OIL						
OTHER						
TOTAL						
GAL WASTE PICKUP/MO	83	83	83	1	83	332
GAL WASTE BURNED/MO						
STORAGE CAPACITY - GAL	500	500	500	1	500	2000
MAX PICKUPS/YR	3	3	3	1	3	12
GAL RE-REFINED OIL PURCHASED/MO						

Table 72. INDUSTRIAL WASTE OIL SUMMARY

COORDINATES 0900 0600 NO. SURVEYS SENT 404 NO. SURVEYS RETURNED 80 19.80%

	SAMPLE LOW	SAMPLE HIGH	SAMPLE TOTAL	NO. REPLIES	SAMPLE AVE	SAMPLE STD DEV	EST POP TOTAL	STD DEV OF EST POP TOTAL
GAL OIL CONSUMED/MO								
GEAR AND TRANS							5507	1564
HYDRAULIC OILS							4531	1034
WATER SOL CUTTING							1086	224
ST CUTTING OIL							1743	1138
TURBINE OIL							154	
MOTOR OIL							18762	2560
OTHER							2127	995
TOTAL							33912	5801
GAL WASTE OIL GEN/MO								
GEAR AND TRANS							4609	1549
HYDRAULIC OILS							1537	407
WATER SOL CUTTING							923	201
ST CUTTING OIL							1008	712
TURBINE OIL							135	
MOTOR OIL							14370	2057
OTHER							1561	817
TOTAL							24145	4929
GAL WASTE REUSED/MO								
GEAR AND TRANS							20	
HYDRAULIC OILS							20	
WATER SOL CUTTING								
ST CUTTING OIL								
TURBINE OIL								
MOTOR OIL								
OTHER								
TOTAL							40	
GAL WASTE PICKUP/MO							24807	3969
GAL WASTE BURNED/MO							5529	1411
STORAGE CAPACITY - GAL							52594	11367
MAX PICKUPS/YR							581	164
GAL RE-REFINED OIL PURCHASED/MO								

APPENDIX J

NETWORK MODELS

NETWORK MODELS *

THE PUP COLLECTION NETWORK

This discussion describes the development of that part of the model which generates the cost of pickup and delivery using local collection trucks to deliver waste oil to the reprocessing plant (PUP system).

The cost of picking up waste in region z and delivering it to the plant in the same vehicle as used for collection (PUP) is:

(1) $$C_{PUPz} = DC_{PUPz} + OH_{PUPz}$$

where: C_{PUPz} = The annual cost of picking up waste in region z and delivering it to the plant for processing ($/yr).

DC_{PUPz} = The annual direct cost of operating the pickup system ($/yr).

OH_{PUPz} = The annual overhead cost associated with operating the pickup system ($/yr).

Overhead Cost

Cost of overhead is estimated as a fraction of the direct cost. Let this fraction be Θ . Then:

(2) $$OH_{PUPz} = \Theta_{PUP} DC_{PUPz}$$

where: Θ_{PUPz} = The overhead factor for the PUP system;

and:

(3) $$C_{PUPz} = (1 + \Theta_{PUP})DC_{PUPz}$$

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* Refer to Tables 46 and 56 (pp. 139, 149 and 150) for the "PUP and PIP System Numerical Parameters".

Direct Cost

Direct cost of operating the PUP system is:

$$(4) \qquad DC_{PUPz} = E_{PUPz} + CL_{PUPz} + INS_{PUPz}$$

where: E_{PUPz} = The cost of the equipment required for operating PUP in region z ($/yr).

CL_{PUPz} = The cost of labor for operating PUP in region z ($/yr).

INS_{PUPz} = The cost of insurance on equipment used for PUP in area z ($/yr).

The collection system model was applied by dividing the State into a number of mutually exclusive geographical regions and operating both the PUP and PIP models to pick up the waste oil generated in each region. Then, with respect to a particular region, the system incurring the least collection cost is the preferred system for that region, and the preferred statewide system is the aggregate of preferred regional systems.

The factors that determine preference for PUP or PIP within a particular region are: distance from the plant, volume of waste oil generated in the region, and the waste oil storage capacity available at the local sources within the region. The farther a region is located from the plant, the more economical the PIP system becomes with respect to PUP. This stems from the fact that when long transit distances to and from the plant are involved, the local collection vehicles of the PUP system spend a great portion of their time in transit so that the larger long haul tractor-trailer combination of the PIP system becomes more attractive, despite the added cost of the intermediate storage tanks. Increased volume of waste oil in a region also has the effect of making the PIP system more attractive, as does small storage capacity for waste oils within a region. Both of these factors tend to increase the time that must be spent by a driver on the local collection circuit and the time spent in transit to and from the plant by local collection vehicles.

In some cases it may be found that PUP will be more economical than PIP in a region located further from the reprocessing plant than another region in which PIP is the more economical system. This situation occurs when the volume of waste oil and pickup frequency in the more remote area is not sufficiently high to justify the PIP system despite the relatively distant location of the region. When this anomaly occurs, it indicates that the more remote PUP region should be combined with the closer PIP region to form one local collection region. This allows the local collection vehicles from the remote PUP region to take advantage of the already justified intermediate storage tanks located between the region and the reprocessing plant.

Both the PUP and PIP models produce fractional answers to the number of local collection and long haul vehicles required. Although obviously not realistic, the fractional number of vehicles provides more insight into the economics of the problem than does an answer in which the number of vehicles required is rounded up to the next whole number. First, fractional numbers of vehicles provide an insight into which regions should be combined with each other from larger, more realistic collection regions. For example, two adjacent regions, each requiring less than one-half of the capacity of one local collection vehicle should realistically be combined into one region that would utilize the capacity of one whole collection vehicle. Secondly, fractional numbers of collection and hauling vehicles required provide insight into the "do in-house" or "contract out" decision that must be made. For example, there may be arguments against combining adjacent collection regions even though the individual regions require only a small part of the capacity of one collection vehicle and/or long haul combination. In such a case, contracting out for the collection and hauling function is obviously attractive from an economic standpoint since it permits the State to purchase only that amount of capacity it needs.

The model can also be run with a provision that all vehicle numbers are rounded to produce an integer answer should this be desired.

In application, the State was initially divided into the 45 master zip code regions (as described in the section on waste oil surveys) and the PUP and PIP systems operated competitively within each region. These collection areas turned out to individually utilize only a small fraction of the capacity of one collection vehicle, or, in the case of the PIP system, of one collection vehicle and one long haul tractor-trailer combination. Therefore, it was more realistic to combine these small regions into a few larger collection regions. Five regions were chosen as being of realistic size and geographical homogeniety. These are portrayed graphically on the outline map of Figures 2 and 7.

Equipment Cost

Cost of equipment required to operate PUP in region z is:

$$(5) \quad E_{PUPz} = N_{PUPz}FC_{PUP} + MI_{PUP}D_{PUPz}\overline{FREQ}_z$$

where: N_{PUPz} = The number of vehicles required to operate the PUP system.

FC_{PUPz} = The fixed annual charge for operating a local collection vehicle required to support PUP in region z ($/vehicle year).

MI_{PUP} = The cost per mile of operating a PUP vehicle ($/mi).

D_{PUPz} = The total distance that must be traveled to make one pickup from all sources in region z and deliver the waste oil picked up to the processing plant (miles/circuit).

$\overline{FREQ}_z$ = The average frequency at which waste must be picked up from sources in region z, if holding tanks are collected only when full.

Distance Traveled by PUP Vehicle in One Collection Circuit

Let: CAP_{zi} = The holding capacity for waste of source i in region z (gallons).

X_{zi} = The average quantity of waste generated by source i in region z, within a year (gal/yr).

z = The number of waste oil sources in region z (sources).

Then the average holding capacity in region z is:

$$\overline{CAP}_z = \frac{1}{m_z} \sum_{i=1}^{m_z} CAP_{zi} \tag{6}$$

The interval at which source i must have its waste collected is:

$$INT_{zi} = \frac{CAP_{zi}}{\overline{X}_{zi}} \tag{7}$$

The frequency with which source i must have its waste collected is:

$$FREQ_{zi} = \frac{1}{INT_{zi}} \tag{8}$$

The average maximum pickup interval in region z is:

$$\overline{INT}_z = \frac{1}{m_z} \sum_{i=1}^{m_z} INT_{zi} \tag{9}$$

And the average minimum pickup frequency in region z is:

(10) $$\mathrm{FREQ}_z = \frac{1}{m_z}\sum_{i=1}^{m_z} \mathrm{FREQ}_{zi}$$

Let: A_z = The area of region z (mi^2)

d_z = The average distance between sources in region z

Then an approximation for d_z is (see Appendix B):

(11) $$d_z = \sqrt{\frac{A_z}{m_z}}$$

Let: R_{zp} = The distance between the center of mass in region z and the plant

Then:

(12) $$R_{zp} = [(X_z - X_p)^2 + (Y_z - Y_p)^2]^{1/2}$$

where: X_z, X_p = The x locations of the center of mass of region z and the plant, respectively.

Y_z, Y_p = The y coordinates of the center of mass of region z and the plant, respectively.

During one collection circuit a local pickup vehicle may collect from $V_{PUP}/\overline{CAP}_z$ sources, on the average. Then, if the capacity of the local collection vehicle, V_{PUP}, is greater than the entire holding capacity of the region, one vehicle may collect wastes from all sources. However, if:

$$V_{PUP} < \overline{CAP}_z m_z$$

the vehicle must make more than one trip to collect wastes from all of the sources. In fact, it must make:

(13) $$\frac{\overline{CAP}_z m_z}{V_{PUP}}$$

complete trips to collect all of the waste.

The total distance traveled between points during a collection circuit by one local collection vehicle is:

$$d_z \left[\frac{V_{PUP}-1}{\overline{CAP}_z}\right] \qquad (14)$$

and empirical evaluations have shown that about $3d_z$ additional distance is traveled in initial and final positioning within a region. Therefore, the average distance traveled by a local collection vehicle within a region during the course of a collection circuit is:

$$d_z \left[\frac{V_{PUP}}{\overline{CAP}_z} + 2\right] \qquad (15)$$

if, $V_{PUP} < \overline{CAP}_z m_z$

and,

$$d_z(m_z+2), \qquad (16)$$

if, $V_{PUP} \geq \overline{CAP}_z m_z$

These expressions for distance traveled within a region during a collection circuit assume a uniform row and column distribution of sources within a region z. If the deviation from uniformity is high, the expression,

$$d_z = \sqrt{A_z/m_z} \qquad (11)$$

will overestimate the distance between sources. Appendix C compares this expression for d_z with the expected d_z in the case of a random distribution of sources.

$3d_z$ was determined experimentally as a factor representative of the additional distance a truck must travel to begin and end work in completing a circuit; e.g., going to and from an overnight truck parking area.

The distance traveled between region z and the plant during each collection circuit is $2R_{zp}$. Therefore, the total distance traveled by one local collection vehicle during one collection cycle is:

$$\text{(17)} \qquad \left\{ Fc_z d_z \left(\frac{V_{PUP}}{\overline{CAP}_z} + 2 \right) + 2Fc_{pz}R_{zp} \right\} \quad \text{if } V_{PUP} < \overline{CAP}_z m_z$$

and,

$$\text{(18)} \qquad \left\{ Fc_z d_z (m_z + 2) + 2Fc_{pz}R_{zp} \right\} \quad \text{if } V_{PUP} \geq \overline{CAP}_z m_z$$

where: Fc_z = A circuity factor representing the absence of direct links connecting all points on a circuit, within a region z.

Fc_{pz} = A circuity factor representing the absence of direct links connecting all points on a circuit (sources), with the plant.

Now, the average total distance required to make a circuit involving collection of waste oil from each source in a region z may be calculated as:

$$\text{(19)} \qquad D_{PUP_z} = \frac{\overline{CAP}_z m_z}{V_{PUP}} \left\{ Fc_z d_z \left(\frac{V_{PUP}}{\overline{CAP}_z} + 2 \right) + 2R_{pz}Fc_{pz} \right\},$$

$$\text{if } V_{PUP} < \overline{CAP}_z m_z ,$$

and:

$$\text{(20)} \qquad D_{PUP_z} = Fc_z d_z (m_z + 2) + 2R_{pz}Fc_{pz} ,$$

$$\text{if } V_{PUP} \geq \overline{CAP}_z m_z$$

Time Required for One Collection Circuit

In this section are derived expressions for the time required to complete one circuit collection from each source in a region, using the collection vehicle to deliver to the plant. The circuit time is comprised of time spent traveling, time spent pumping and time spent waiting, hooking up, unhooking, etc. at each source and at the plant.

The time spent traveling per circuit is:

$$\text{(21)} \qquad \frac{\overline{CAP}_z m_z}{V_{PUP}} \left\{ \frac{Fc_z d_z}{SL_{PUPz}} \left(\frac{V_{PUP}}{\overline{CAP}_z} + 2 \right) + \frac{2R_{zp} Fc_{pz}}{SR_{PUPz}} \right\}$$

$$\text{if } V_{PUP} < \overline{CAP}_z m_z$$

and:

$$\text{(22)} \qquad \frac{Fc_z d_z (m_z + 2)}{SL_{PUPz}} + \frac{2R_{pz} Fc_{pz}}{SR_{PUPz}}$$

$$\text{if } V_{PUP} \geq \overline{CAP}_z m_z$$

where: SL_{PUPz} = The average speed of the collection vehicle within region z (mi/hr).

SR_{PUPz} = The average speed of the collection vehicle between region z and the plant (mi/hr).

The total time spent pumping during one collection circuit and at the plant is:

$$\text{(23)} \qquad \frac{2m_z \overline{CAP}_z}{PR_{PUP}}$$

where: PR_{PUP} = The pumping rate of the collection vehicle (gal./hr).

Time spent waiting is:

$$\text{(24)} \qquad m_z w_s + \frac{m_z \overline{CAP}_z}{V_{PUP}} W_p \qquad \text{if } V_{PUP} < \overline{CAP}_z m_z$$

and,

(25) $m_z w_s + W_p$ if $V_{PUP} \geq \overline{CAP}_z m_z$

where: w_s = The average waiting time at a source (hrs/visit).

W_p = The average time at the plant (hrs/visit).

The total time required to complete one circuit may now be calculated as:

$$(26)\quad T_{PUP_z} = \Bigg[\Bigg[\Bigg\{\frac{Fc_z d_z\,(m_z + 2)}{SL_{PUPz}} + \frac{2R_{zp}Fc_{pz}}{SR_{PUPz}}\Bigg\} + \frac{2m_z\overline{CAP}_z}{PR_{PUPz}} + m_z w_s + W_p\Bigg]\frac{1}{8760},$$

$$\text{if } V_{PUP} \geq \overline{CAP}_z m_z,$$

and

$$(27)\quad T_{PUPz} = \Bigg[\frac{\overline{CAP}_z m_z}{V_{PUP}}\Bigg\{\frac{Fc_z d_z}{SL_{PUPz}}\left(\frac{V_{PUP}}{\overline{CAP}_z} + 2\right) + \frac{2R_{zp}Fc_{pz}}{SR_{PUPz}}\Bigg\} + \frac{2m_z\overline{CAP}_z}{PR_{PUPz}} + m_z w_s + \frac{m_z\overline{CAP}_z}{V_{PUP}}\,W_p\Bigg]\frac{1}{8760}$$

$$\text{if } V_{PUP} < \overline{CAP}_z m_z,$$

where: $\frac{1}{8760}$ = The constant required to convert hours into years.

The Number of Local Collection Vehicles Needed Under the PUP System to Service a Region, z.

The number of vehicles needed to service a region z may now be calculated by dividing the time required to service all of the sources in region z by the required interval at which these sources must be serviced. Therefore,

$$N_{PUPz} = \frac{T_{PUPz}}{INT_z} \tag{28}$$

where: N_{PUPz} = The number of vehicles required to service region z.

But this assumes that the vehicles are available for use 24 hours per day and that, on the average, a source is serviced just as the waste holding tank is full. It seems reasonable to assume that sources can be serviced no more than during some fractional part of each day, and that a collection safety factor should be applied to reduce the number of times a vehicle must be dispatched on an emergency basis to a source to prevent its waste holding tank from overflowing. Provision may be made for these allowances by computing N_{PUPz} as:

$$N_{PUPz} = \frac{T_{PUPz}}{\gamma_{PUP}\Omega_{PUP}\overline{INT}_z} \tag{29}$$

where: γ_{PUP} = The utilization factor for the vehicles.

Ω_{PUP} = The overdesign factor

It may be noted in this and subsequent expressions that a small interval ($\overline{INT}_z$) and the corresponding large frequency ($\overline{FREQ}_z$) tends to increase the cost of the collection system; in other words, make the model more conservative. In this interest, the following computation for $\overline{FREQ}_z$ was used in actual application of the model:

$$\overline{FREQ}_z = \max \left\{\frac{1}{m_z} \sum_i FREQ_{zi};\ \sum_i x_{zi} / \sum_i CAP_{zi}\right\} \tag{30}$$

Sufficient information is now available to compute the equipment cost (E_{PUPz}) for the PUP system in accordance with expression (5).

Cost of Labor

The cost of labor may be calculated, on an annual basis, as the time required to make one circuit, multiplied by the frequency with which the circuits must be completed; times the hourly labor rate; all multiplied by the number of workers required to support one local collection vehicle. Thus:

$$(31) \qquad CL_{PUPz} = [T_{PUPz}\,\overline{FREQ}_z] \cdot [ND_{PUP}LD_{PUP}+LSW_{PUP}]\ (8760)$$

where: ND_{PUP} = The number of drivers/vehicle.

NSW_{PUP} = The number of support workers/vehicle.

LD_{PUP} = The hourly labor cost of drivers (\$/hr).

LSW_{PUP} = The hourly labor cost of support workers (\$/hr).

It may be preferable to have more than one driver per vehicle for training and other contingency purposes. However, it should be remembered that the hourly labor cost includes costs accrued due to sick leave and vacation times normally encountered. Another equivalent computation of labor costs that may be used is:

$$(32) \qquad CL_{PUPz} = N_{PUPz}\gamma_{PUP}(ND_{PUP}LD_{PUP}+NSW_{PUP}LSW_{PUP})\ (8760)$$

Insurance Cost

The total cost of insuring the local collection vehicles is a constant charge per vehicle. Thus:

$$(33) \qquad INS_{PUPz} = INS_{PUP}N_{PUPz}$$

where: INS_{PUP} = The cost of insuring a local collection vehicle.

Overall PUP System Cost

All of the components necessary to compute the total annual cost for operating the PUP system within a particular region, in accordance with expression (1), have now been developed. Costs for all regions using the PUP system may be calculated by summing over z. Thus:

$$C_{PUP} = \sum_{z} C_{PUPz} \tag{34}$$

Should separate PUP systems be used to collect different types of waste, the elements of the cost equation developed thus far should be appended with another subscript j for the jth category of wastes and:

$$C_{PUPz} = \sum_{j} C_{PUPjz} \tag{35}$$

$$C_{PUP} = \sum_{j} \sum_{z} C_{PUPjz} \tag{36}$$

$$C_{PUPj} = \sum_{j} C_{PUPjz} \tag{37}$$

Table 73. TABLE OF SYMBOLS FOR THE PUP SYSTEM

PUP SYSTEM:	A system whereby local collection vehicles pick up wastes at the sources and deliver the wastes to the reprocessing plant.
C_{PUPz}:	The annual operating cost for the PUP system in region z. (\$/yr.).
DC_{PUPz}:	The annual direct cost of operating the PUP system in region z. (\$/yr.).
OH_{PUPz}:	The annual overhead cost of operating the PUP system in region z. (\$/yr.).
Θ_{PUP}:	The ratio of PUP overhead to PUP direct costs. $\Theta_{PUP} = OH_{PUPz}/DC_{PUPz}$ for all z.
E_{PUPz}:	The annual operating cost of equipment required to support the PUP system in region z. (\$/yr.).
CL_{PUPz}:	Labor cost for operating PUP in region z. (\$/yr.).
INS_{PUPz}:	The annual cost of insurance on PUP vehicles in region z. (\$/yr.).
N_{PUPz}:	The number of local collection vehicles required to support PUP in region z.
FC_{PUP}:	The fixed annual lease charge for a local collection vehicle. (\$/vehicle yr.).
MI_{PUP}:	The lease cost per mile for a local collection vehicle. (\$/mi.).
D_{PUPz}:	The total distance traveled by local collection vehicle to collect from all sources in region z and deliver to the reprocessing plant. (miles/circuit).
$\overline{FREQ}_z$:	The average waste collection frequency required at a waste source in region z, if the waste tank is collected when full.
CAP_{zi}:	The waste storage capacity of source i in region z (gal.).

Table 73 (Continued). TABLE OF SYMBOLS FOR THE PUP SYSTEM

X_{zi}:	The average generation rate of waste oil by source i in region z (gal./yr.).
m_z:	The number of waste generation sources in region z.
$\overline{CAP}_z$:	The average holding capacity of waste sources in region z. (gallons).
$\overline{INT}_z$:	The average interval between collections at sources in region z, if collections are made only when the waste storage tank is full. (yrs./collection).
A_z:	The area of region z (mi^2).
d_z:	The average straight line distance between waste sources in region z (mi.).
R_{zp}:	The straight line distance between region z and the reprocessing plant. (mi.).
$Fc_z:Fc_{pz}$	A circuitry factor representing the difference between travel over an actual road and the straight line distance between sources on a collection circuit in region z, and between region z and the plant, respectively.
V_{PUP}:	The capacity of the local collection vehicle used in the PUP system. (gal./vehicle).
SL_{PUPz}:	The average speed of a local collection vehicle between stops in region z. (mi./hr.).
SR_{PUPz}:	The average speed of a local collection vehicle between region z and the reprocessing plant. (mi./hr.).
PR_{PUP}:	The pumping rate for a local collection vehicle. (gal./hr.).
w_s:	The average waiting or dead time spent by a local collection vehicle connecting and disconnecting at each local source. (hrs./collection).

Table 73 (Continued). TABLE OF SYMBOLS FOR THE PUP SYSTEM

w_p:	The average waiting or dead time a vehicle spends at the reprocessing plant in off-loading. This includes analysis time. (hrs./load).
γ_{PUP}:	The utilization factor for local collection vehicles. The percentage of time vehicle is in use.
Ω_{PUP}:	The overdesign factor. The ratio of the number of vehicles required to support the PUP system on the average to the number actually employed.
ND_{PUP}:	The number of drivers maintained for each local collection vehicle. (drivers/vehicle).
LD_{PUP}:	The labor cost for drivers of local collection vehicles. ($/hr.).
NSW_{PUP}:	The number of supporting workers maintained per local collection vehicle. (workers/vehicle).
LSW_{PUP}:	The labor cost for local collection vehicle support workers. ($/hr.).

THE PIP COLLECTION NETWORK

The annual cost of having local collection pickup vehicles deliver to an intermediate storage tank, with long haul vehicles delivering to plant from intermediate storage tanks (the PIP system), in a region z, may be written as:

(38) $$C_{PIPz} = C_{PIz} + C_{ISTz} + C_{IPz}$$

where: C_{PIPz} = The annual cost of operating the PIP system in region z ($/yr).

C_{PIz} = The annual cost of operating the local collection system supporting the PIP system in region z ($/yr).

C_{ISTz} = The annual cost of the intermediate storage tank for region z ($/yr).

C_{IPz} = The annual cost of the long haul system for hauling waste oil from the intermediate storage tank in region z, to the plant ($/yr)

Cost of the Local Collection System

The cost of the local collection system (PI system) may be written as:

(39) $$C_{PIz} = DC_{PIz} + OH_{PIz}$$

or,

(40) $$C_{PIz} = DC_{PIz} (1 + \theta_{PI})$$

where: DC_{PIz} = The direct cost of the PI system ($/yr).

OH_{PIz} = The overhead cost of the PI system ($/yr).

θ_{PI} = The overhead multiplier - that is:

$$OH_{PIz} = \theta_{PI} DC_{PIz}$$

Direct Cost

The direct cost for the PI system in region z is:

$$DC_{PIz} = E_{PIz} + CL_{PIz} + INS_{PIz} \tag{41}$$

where: E_{PIz} = The annual cost of equipment required for the PI system in region z (\$/yr).

CL_{PIz} = The cost of labor for operating the PI system in region z (\$/yr).

INS_{PIz} = The cost of insurance on local collection vehicles (\$/yr).

Cost of Equipment

$$E_{PIz} = N_{PUPz}FC_{PUP} + MI_{PUP}D_{PIz}\overline{FREQ}_z \tag{42}$$

where: N_{PUPz} = The number of local collection vehicles required to support the PI system in region z (vehicles).

FC_{PUP} = The fixed annual charge for operating a local collection vehicle (\$/vehicle year).

MI_{PUP} = The cost per mile of operating a local collection vehicle (\$/mi).

D_{PIz} = The total distance that must be traveled to make one collection from all sources in region z using the PI system (mi/circuit).

$\overline{FREQ}_z$ = The average waste collection frequency required at a waste source in region z, if the waste tank is collected when full.

Distance Traveled by PI Vehicle in One Collection Circuit

The distance traveled by a local collection vehicle during one circuit under the PI system is derived similarly to that for the PUP system except that the local collection vehicle does not deliver to the plant each circuit, but rather delivers to an intermediate storage tank (IST) located in the region. Thus, the distance traveled during a complete circuit is:

$$(43) \qquad D_{PIz} = \frac{\overline{CAP}_z m_z Fc_z}{V_{PUP}} \left\{ d_z \left(\frac{V_{PUP}}{\overline{CAP}_z} + 2 \right) \right\} \qquad \text{if } V_{PUP} < \overline{CAP}_z m_z$$

and,

$$(44) \qquad D_{PIz} = Fc_z \left\{ d_z (m_z + 2) \right\} \qquad \text{if } V_{PUP} \geq \overline{CAP}_z m_z$$

where: The symbols are defined in the Table of Symbols.

Time Required for a Local Collection Circuit

The expression for time required to complete one circuit, collecting from each source in region z and delivering to the IST is derived next. It is similar to that for the PUP system except that those factors associated with delivery to the plant are omitted.

$$(45) \qquad T_{PIz} = \left[\frac{\overline{CAP}_z m_z Fc_z d_z}{V_{PUP} SL_{PUPz}} \left(\frac{V_{PUP}}{\overline{CAP}_z} + 2 \right) + \frac{2 m_z \overline{CAP}_z}{PR_{PUP}} + (m_z + 1) w_s \right] \frac{1}{8760}, \qquad \text{if } V_{PUP} < m_z \overline{CAP}_z$$

and,

$$(46) \qquad T_{PIz} = \left[\frac{Fc_z d_z (m_z + 2)}{SL_{PUPz}} + \frac{2 m_z \overline{CAP}_z}{PR_{PUP}} + (m_z + 1) w_s \right] \frac{1}{8760}, \qquad \text{if } V_{PUP} \geq m_z \overline{CAP}_z$$

where: The symbols are defined in the Table of Symbols.

The Number of Local Collection Vehicles Needed for the PI System

The number of local collection vehicles needed to service region z under the PI system is:

$$N_{PIz} = \frac{T_{PIz}}{\gamma_{PI}\Omega_{PI}INT_z} \tag{47}$$

where: N_{PIz} = The number of local collection vehicles required to service region z under the PI system. The remaining symbols are defined similarly, as in equation (29).

Cost of Labor

The cost of labor for the PI system may be calculated as:

$$CL_{PIz} = T_{PIz}\,\overline{FREQ}_z\,[ND_{PUP}LD_{PUP}+NSW_{PUP}LSW_{PUP}]\;8760 \tag{48}$$

or,

$$CL_{PIz} = N_{PUTz}\gamma_{PUP}\,(ND_{PUP}LD_{PUP}+NSW_{PUP}LSW_{PUP})\;8760 \tag{49}$$

where: The symbols are defined in the Tables of Symbols, (PUP and PIP).

Insurance Cost

Cost of insuring the local collection vehicles required for the PI system is:

$$INS_{PIz} = INS_{PUP}N_{PIz} \tag{50}$$

Overall PI System Cost

Sufficient information is now available to compute the local collection system for the PIP concept according to expression (39).

Cost of the Intermediate Storage Tank (IST)

All financing costs for the IST's are accumulated in the profit model. Refer to Appendix J for determination of the size of intermediate storage tanks.

The annual cost of the intermediate storage tank (IST) to service region z under the PIP system is expressed as:

$$C_{ISTz} = \Phi_{IST} I_{ISTz} + DEP_{ISTz} \tag{51}$$

where: I_{ISTz} = The capital cost of the IST, its land and attentant facilities required to serve region z under the PIP concept ($).

Φ_{IST} = A multiplier used to calculate annual operating and maintenance cost of an IST based on the original investment in the IST (1/yr).

DEP_{ISTz} = The annual depreciation allowance for the IST serving region z under the PIP concept ($/yr).

The IST investment cost may be expressed as:

$$I_{ISTz} = E_{ISTz} + SD_{ISTz} + Eng_{ISTz} + Land_{ISTz} \tag{52}$$

where: E_{ISTz} = The cost of materials and construction ($).

SD_{ISTz} = The cost of site development ($).

Eng_{ISTz} = The cost of engineering and fee ($).

Cost of Construction and Materials

The cost of the construction and materials required for the IST required to service region z under the PIP system may be calculated as:

$$E_{ISTz} = a_{io} + a_{i1}V_{ISTz} \tag{53}$$

where: a_{io} = A constant for the ith range of volume ($).

a_{i1} = A constant for the ith range of volume ($/gal).

V_{ISTz} = The volume of the IST required to service region z (gal).

There are two ranges of volume that are of interest to the PIP system: 0 to 100,000 gallons and 100,000 to 1,000,000 gallons. These two ranges are important because once a tank becomes greater than 100,000 gallons in capacity, the cost per unit volume drops significantly. The values of a_{ij} and their corresponding range of volumes are shown below:

IST Construction and Material Cost Constants

Volume Range	i	a_{io},	a_{i1}
0 - 100,000 gal.	1	0.0	.392
100,000 - 1,000,000 gal.	2	14,262	.0511

Site Development Costs, Engineering Costs, and Fee

The cost of site development, engineering and the fee charged are computed as percentages of the construction and material costs. Thus:

$$SD_{ISTz} = \varepsilon_1 E_{ISTz} \tag{54}$$

$$Eng_{ISTz} = \varepsilon_2 E_{ISTz} \tag{55}$$

where: ε_j: $j = 1,2$ = constants

Cost of Land

The cost of land is computed as a function of the tank diameter and the set back around the tank. The cost of land required for the IST in region z is discussed next.

The height of the IST is taken to be 1.2 times the diameter. Thus, diameter can be expressed as a function of volume such that:

$$\text{Diameter} = .521V^{1/3} \quad (\text{V in gals.}) \tag{56}$$

Using this relationship, the cost of IST land may be written as:

$$\mathrm{Land}_{ISTz} = \mathrm{Cl}_{ISTz}\,[.521V_{ISTz}^{1/3} + SB_{IST}]^2 \tag{57}$$

where: Cl_{ISTz} = The cost of land in region z at the IST site ($\$/ft^2$).

SB_{IST} = The set back around an IST (ft).

Cost of Parking Area

The size of the parking area is taken as a function of the volume of the IST such that the land area of the parking lot is calculated as:

$$g_{ISTz}V_{ISTz} \tag{58}$$

where: g_{ISTz} = a constant (ft^2/gal).

Then the cost of the parking area is:

$$PL_{ISTz} = \mathrm{Cl}_{ISTz}\,g_{ISTz}V_{ISTz} \tag{59}$$

The total initial investment associated with the IST serving region z is calculated as:

$$I_{ISTz} = [\,1 + \sum_{j=1}^{3} \epsilon_j]\,(a_{io} + a_{i1}V_{ISTz}) \; + \tag{60}$$

$$+ \; \mathrm{Cl}_z\,\{[.521V_{ISTz}^{1/3} + SB_{ISTz}]^2 + g_{IST}V_{ISTz}\}$$

Depreciation Allowance

Depreciation allowance is determined on a straight line basis over the estimated life of the IST. Thus:

$$DEP_{ISTz} = E_{ISTz} (1 - \lambda_{IST})/y_{IST} \tag{61}$$

where λ_{IST} = The salvage value of the IST at the end of its useful life, expressed as a fraction of the initial investment cost.

y_{IST} = The estimated useful life of the IST (yrs).

Total Operating Cost of IST_z

Sufficient information is now available in the form of expressions (52) through (61) to substitute into equation (51) giving the annual cost of the IST in region z supporting the PIP system in that region.

Cost of Hauling Wastes from the Intermediate Storage Tank to the Plant (The IP System)

Alternatives for barging and pipelining have been examined. See Appendix I.

The cost of the IP system may be written in a form similar to that used for the local collection system; that is:

$$C_{IPz} = DC_{IPz} + OH_{IPz} \tag{62}$$

or,

$$C_{IPz} = DC_{IPz} (1 + \theta_{IP}) \tag{63}$$

where: DC_{IPz} = The direct cost of the IP system ($/yr).

OH_{IPz} = The overhead cost of the IP system ($/yr).

θ_{IP} = The overhead multiplier. That is:

$$OH_{IPz} = \theta_{IP} DC_{IPz}$$

Direct Cost

The direct cost for the IP system in region z is:

$$DC_{IPz} = E_{IPz} + CL_{IPz} + INS_{IPz} \tag{64}$$

where: E_{IPz} = The annual cost of equipment required for the IP system in region z ($/yr).

CL_{IPz} = The cost of labor operating the IP system in region z ($/yr).

INS_{IPz} = The cost of insurance on the IP vehicles operating in region z ($/yr).

Cost of Equipment

$$E_{IPz} = N_{IPTz}FC_{IPT} + N_{IPRz}FC_{IPR} + D_{IPz}\,(MI_{IPT} + MI_{IPR}) \tag{65}$$

where: N_{IPT} = The number of long haul trailers (IPT) required to support the IPI system in region z (trailers).

FC_{IPT} = The annual fixed charge for operating a long haul trailer ($/trailer yr).

MI_{IPT} = The cost per mile of operating a long haul trailer ($/mi).

D_{IPz} = The distance traveled by long haul vehicle between the IST in region z and the plant, over the course of a year. (Note that this definition of distance traveled differs from that used in the local collection calculation) (mi/yr).

N_{IPRz} = The number of long haul tractors (IPR) required to support the PIP system in region z (vehicles).

FC_{IPRz} = The annual fixed charge for operating a long haul tractor ($/tractor yr).

MI_{IPR} = The cost per mile of operating a long haul tractor ($/mi).

Distance Traveled by Long Haul Vehicles Between Intermediate Storage Tanks in Region z and Plant

The distance traveled on one round trip between ISTz and the plant is:

(66) $$2Fc_{pz}R_{zp}$$

The quantity of waste carried in this trip is V_{IP}, the capacity of the long haul vehicle. The amount of waste that must be transported between the IST and the plant during one year is:

$$x_z'$$

where: x_z' = The total quantity of waste oil generated by all sources in region z.

Thus:

(67) $$x_z' = \sum_{i=1}^{m_z} x_{zi}$$

where: x_{zi} = The average amount of waste generated by source i in region z within a year (gal./yr).

It follows that the number of trips made by the long haul vehicles is:

$$\frac{x_z'}{V_{IP}}$$

so that:

(68) $$D_{IPz} = \frac{x_z' \, 2Fc_{pz}R_{zp}}{V_{IP}}$$

Time Required for Long Haul Vehicles to Transport Waste from IST to Plant

The time required for one round trip of the IP vehicle is:

$$\left\{ \frac{2Fc_{pz}}{SR_{IPz}} + \frac{2V_{IP}}{PR_{IP}} + w_s + w_p \right\} \frac{1}{8760}$$

Then, the total long haul vehicle time required per year is:

$$T_{IPz} = \frac{x_z'}{V_{IP}} \left\{ \frac{2Fc_{pz}R_{zp}}{SR_{IPz}} + \frac{2V_{IP}}{PR_{IP}} + w_s + w_p \right\} \frac{1}{8760} \qquad (69)$$

where: T_{IPz} = The time long haul vehicle(s) must spend transporting waste from the IST to the plant over the course of a year (years).

Number of Long Haul Trailers Required

The number of long haul trailers required to support the PIP system in region z is:

$$N_{IPTz} = \frac{T_{IPz}}{\gamma_{IPT}\Omega_{IPT}} \qquad (70)$$

where: N_{IPTz} = The number of long haul trailers required to support the IP system in region z .

γ_{IPT} = The utilization factor for IP vehicles.

Ω_{IPT} = The overdesign factor.

Number of Long Haul Tractors Required

Since the long haul tractors may be detached from the long haul trailers, a savings will accrue if tractors are detached and dispatched immediately on the next leg of their journey during their available hours while the trailers wait to be pumped out. The number of tractors required is:

$$(71) \qquad N_{IPR} = \frac{T_{IPz} - \dfrac{x_z' \left(w_s + W_p + \dfrac{2V_{IP}}{PR_{IP}}\right)}{V_{IP}\,(8760)}}{\gamma_{IPR}\Omega_{IPR}}$$

where: N_{IPR} = The number of long haul tractors required to support the IP system in region z.

Cost of Labor

The cost of labor required to operate the IP system in region z is:

$$(72) \qquad CL_{IPz} = \{N_{IPTz}\gamma_{IPT}\,[(NSW_{IPT})\,(LSW_{IPT})] + N_{IPRz}\gamma_{IPR}\,[(ND_{IPR})\,(LD_{IPR}) + (NSW_{IPR})\,(LSW_{IPR})]\}\ 8760$$

where: NSW_{IPT} = The number of support workers required per trailer (workers/trailer).

NSW_{IPR} = The number of support workers required per long haul tractor (workers/tractor).

ND_{IPR} = The number of drivers required per long haul tractor (drivers/tractor).

LSW_{IPT} = The labor cost per support worker on a trailer (\$/hr).

LSW_{IPR} = The labor cost per support worker on a tractor (\$/hr).

LD_{IPR} = The labor cost per driver of a long haul tractor (\$/yr).

Cost of Insurance

Insurance costs for the IP system are calculated for region z as:

(73) $$INS_{IPz} = N_{IPTz} INS_{IPT} + N_{IPRz} INS_{IPR}$$

where: INS_{IPT} = The cost of insurance per long haul trailer ($/yr trailer).

INS_{IPR} = The cost of insurance per long haul tractor ($/yr tractor).

Total IP System Cost

Sufficient information has been developed through expressions (64) through (73) to compute IP system operating costs in accordance with equation (62).

Total PIP System Cost

Equations (39), (51) and (62) may be summed in accordance with equation (38.) to calculate total annual PIP system cost.

Table 74. TABLE OF SYMBOLS FOR THE PIP COLLECTION NETWORK

PIP System:	A system whereby a local collection vehicle picks up waste from sources within a region, and delivers the waste to an intermediate storage tank within the region. Larger, long-haul vehicles then pick up the waste from the intermediate storage tank and deliver it to the reprocessing plant. The PIP system is comprised of three subsystems: 1) the PI system; 2) the IST system; and 3) the IP system.
PI Subsystem:	That component of the PIP system that involves picking up waste from local sources and delivering it to the intermediate storage tank.
IST Subsystem:	That component of the PIP system that involves storing the waste collected in a region in an intermediate storage tank.
IP Subsystem:	That component of the PIP system that involves picking up waste at an intermediate storage tank and delivering it to the reprocessing plant.
C_{PIPz}:	The annual cost of operating the PIP system in region z. (\$/yr.).
C_{PIz}:	The annual cost of operating the PI subsystem in region z. (\$/yr.).
C_{ISTz}:	The annual cost of operating the IST subsystem in region z. (\$/yr.).
C_{IPz}:	The annual cost of operating the IP subsystem in region z. (\$/yr.).
DC_{PIz}:	The annual direct cost of operating the PI subsystem in region z. (\$/yr.).
OH_{PIz}:	The annual overhead cost of operating the PI subsystem in region z. (\$/yr.).
Θ_{PI}:	The ratio of PI overhead to PI direct cost, i.e., $PH_{PIz} = \Theta_{PI} DC_{PIz}$.

Table 74 (Continued). TABLE OF SYMBOLS FOR THE PIP COLLECTION NETWORK

PI_{ISTz}:	The initial investment cost of the intermediate storage tank and its facilities supporting the IST subsystem in region z. ($).
DEP_{ISTz}:	The annual depreciation allowance for the intermediate storage tank in region z. ($/yr.).
E_{ISTz}:	The cost of material and construction for the intermediate storage tank supporting the IST system in region z. ($).
SD_{ISTz}:	The cost of site development for the intermediate storage tanks and its facilities in region z. ($).
ENG_{ISTz}:	The cost of engineering services and fee associated with construction of the intermediate storage tanks in region z. ($).
$Land_{ISTz}$:	The cost of land on which the intermediate storage tanks are located. ($).
E_{PIz}:	The annual cost of equipment required to support the PI system in region z. ($/yr.).
CL_{PIz}:	The cost of labor required to operate the PI system equipment in region z. ($/yr.).
INS_{PIz}:	The cost of insurance on PI system vehicles in region z. ($/yr.).
N_{PUTz}:	The number of local collection vehicles required to support the PI system in region z. (vehicles).
D_{PIz}:	The distance traveled by PI vehicles in the course of collecting from all sources in region z once. (mi./circuit).
T_{PIz}:	The time spent by PI vehicles in collecting from all sources in region z once. (yrs./circuit).
C_{ISTz}:	The annual cost of operating the IST system in region z. ($/yr.).

Table 74 (Continued). TABLE OF SYMBOLS FOR THE PIP COLLECTION NETWORK

Φ_{IST}:	The ratio of annual cost of maintenance and operation of an intermediate storage tank to the investment cost of an intermediate storage tank.
PL_{ISTz}:	The cost of peripheral land (used for parking, etc.) for the intermediate storage tank located in region z. ($).
V_{ISTz}:	The capacity of the intermediate storage tank in region z. (gal.).
A_{io}, A_{i1}:	Construction and material cost constants associated with an intermediate storage tank of the ith capacity range. ($, and $/gal.).
E_1, E_2, E_3:	Site development, engineering and fee cost constants associated with an intermediate storage tank.
Cl_{ISTz}:	Cost of land used for the intermediate storage tank used in region z. ($/ft^2).
SB_{IST}:	The set back required around an intermediate storage tank. (ft.).
g_{IST}:	The intermediate storage tank parking lot size contant. (ft^2/gal.).
λ_{IST}:	The ratio of salvage value to initial investment cost for an intermediate storage tank site.
y_{IST}:	The expected usedful life of an intermediate storage tank facility. (yrs.).
DC_{IPz}:	The annual direct operating cost for the IP system in region z. ($/yr.).
OH_{IPz}:	The annual overhead cost of the IP system in region z.

Table 74 (Continued). TABLE OF SYMBOLS FOR THE PIP COLLECTION NETWORK

Θ_{IPz}:	The ratio of IP overhead cost to direct cost, i.e. $OH_{IPz} = \Theta_{IP} DC_{IPz}$.
E_{IPz}:	The annual cost of equipment required to support the IP system in region z.
CL_{IPz}:	The annual cost of labor required to operate the IP system equipment. (\$/yr.).
INS_{IPz}:	The cost of insurance on IP system vehicles. (\$/yr.).
N_{IPTz}:	The number of long-haul trailers required to support the IP system in region z.
FC_{IPT}:	The fixed annual lease charge for a long-haul trailer. (\$/trailer/yr.).
MI_{IPT}:	The lease cost per mile for a long-haul trailer. (\$/mi.).
D_{IPz}:	The round trip distance traveled by a long-haul tractor-trailer combination between the intermediate storage tank and the reprocessing plant in one trip. (mi./circuit).
N_{IPRz}:	The number of long-haul tractors required to support the IP system in region z.
FC_{IPR}:	The annual fixed lease cost for one long-haul tractor. (\$/ yr.)
MI_{IPR}:	The lease cost per mile for a long-haul tractor. (\$/mi.)
X'_z :	The total quantity of waste generated within region z in one year. (gal./yr.).
T_{IPRz}:	The total long-haul trailer time required to support the IP system for a year. (tractor yrs.)
V_{IP}:	The capacity of one long-haul trailer. (gal./trailer).

Table 74 (Continued). TABLE OF SYMBOLS FOR THE PIP COLLECTION NETWORK

Ω_{IPR}:	The overdesign factor. The ratio of the number of vehicles required to support the IP system, on the average, to the number actually employed.
γ_{IPT}:	The utilization factor for long-haul vehicles. The percentage of time the vehicle is in use.
Ω_{IPT}:	The overdesign factor. The ratio of the number of vehicles required to support the IP system, on the average, to the number actually employed.
γ_{IPR}:	The utilization factor for long-haul tractors. The percentage of time the vehicle is in use.
T_{IPTz}:	The total long-haul trailer time required to support the IP system for a year. (trailer yrs.)
N_{IPT}:	The number of long-haul trailers required to support the IP system.
NSW_{IPT}:	The number of support workers required per long-haul trailer.
N_{IPR}:	The number of long-haul tractors required to support the IP system.
NSW_{IPR}:	The number of support workers required per long-haul tractor.
ND_{IPR}:	The number of drivers required per long-haul tractor.
LSW_{IPT}, LSW_{IPR}:	The hourly labor cost for long-haul trailer and tractor support workers respectively. (\$/hr.).
LD_{IPR}:	The hourly labor cost for long-haul tractor drivers. (\$/hr.).
INS_{IPT}:	The annual cost of insuring a long-haul trailer. (\$/trailer yr.).
INS_{IPR}:	The annual cost of insuring a long-haul tractor. (\$/tractor yr.).
γ_T:	The utilization factor for short-haul trucks.

$$r = \frac{V_{ID}}{V_{PUP}}$$

Distribution System

The distribution system is the collection system in reverse. It is envisioned, however, that products will be distributed only to large volume users of the reprocessed products so that a local distribution system will not be required. It seems most likely that only the long haul portion of the PIP system will be used to deliver the products produced by the waste oil reprocessing system directly to large volume users.

In the case where long haul vehicles are used to deliver products directly to users, the annual cost of delivery to this rth customer is:

$$C_{DELr} = (1 + \Theta_{PLr})\, DC_{DELr} \tag{74}$$

where: C_{DELr} = The annual cost of delivery to the rth customer ($/yr).

Θ_{PLr} = The delivery system overhead factor

DC_{DELr} = The annual direct cost of delivery to the rth customer ($/yr).

The direct cost of delivering to the rth customer is given by:

$$DC_{DELr} = E_{DELr} + CL_{DELr} + INS_{DELr} \tag{75}$$

The symbols used in this equation are the same and have the same meanings as those used in the collection system model except for the subscripts. This convention will be used throughout the delivery system cost model. New symbols will be defined where used.

The components of equation (75) are defined as:

$$INS_{DELr} = N_{DELTr} INS_{DELT} + N_{DELRr} INS_{DELRr} \tag{76}$$

$$\begin{aligned} CL_{DELr} = {} & \{N_{DELTr} Y_{DELT} [(NSW_{DELT})(LSW_{DELT}] + \\ & + N_{DELRr} Y_{DELR} [(ND_{DELr} LD_{DELR}) + \\ & + (NSW_{DELR})(LSW_{DELR})] \end{aligned} \tag{77}$$

(78) $$E_{DELr} = N_{DELTr}FC_{DELT} + N_{DELRr}FC_{DELR} + D_{DELr}\,(MI_{DELT} + MI_{DELR})$$

(79) $$N_{DELTr} = \frac{Y_r}{\gamma_{DELT}\Omega_{DELT}V_{DEL}}\left\{\frac{2Fc_{rp}R_{rp}}{SR_{DELr}} + \frac{2V_{DEL}}{RR_{DEL}} + w_r + W_p\right\}\left(\frac{1}{8760}\right)$$

(80) $$N_{DELRr} = \frac{Y_r}{\gamma_{DELR}\Omega_{DELR}V_{DEL}}\left\{\frac{2Fc_{rp}R_{rp}}{SR_{DELr}}\right\}\left(\frac{1}{8760}\right)$$

where: Y_r = The amount of oil delivered to customer r (gal./yr).

and, finally:

(81) $$D_{DELr} = \frac{Y_r 2Fc_{rp}R_{rp}}{V_{DEL}}$$

This formulation assumes that deliveries are made to customers in trailer load lots; that is to say, small users of oil who are able to take only partial trailer load lots are not supplied with this system. This assumption is consistant with the findings of the market survey, which indicates that a viable market for reprocessed oils is the fuel oil market, and that there are a sufficient number of large users of fuel oil in the State of Maryland to absorb all of the output of the waste oil reprocessing system. This is probably true for most states, particularly northern states.

Should it be desired to service a market of small customers, however, the delivery cost model may be expanded to a full service model equivalent to the PIP and PUP systems used to collect waste oil.

Table 75. RELATIVE PLANT ALTERNATIVE LOCATIONS AND DISTANCES TO REGIONS

Region	Name	Location Coordinates	Distance to Plant Location 1 925.495. Baltimore (Foreman's Corner) (miles)	Distance to Plant Location 2 800.300. Waldorf (miles)	Distance to Plant Location 3 827.475. Columbia (miles)
1	Northwest	690.580.	47.48	57.16	32.80
2	Central	827.475	19.00	33.64	0.0
3	North	925.495.	0.0	51.16	18.10
4	South	800.300.	44.01	0.0	33.64
5	Eastern Shore	925.495.	38.96	52.17	51.92

APPENDIX K

SUMMARY OF
COST, REVENUE AND PROFIT (CRP) MODEL EQUATIONS

Table 76. SUMMARY OF COST, REVENUE & PROFIT (CRP) MODEL EQUATIONS

REPROCESSING PLANT AND TANK FARM COST

Cost of Land for Plant and Tank Farm

(3) $$\text{Land}_{PLTFi} = Cl_{PLTFi}\, A_{PLTFi}$$

Plant and Tank Farm Construction Cost

(4) $$E_{PLTFi} = E_{PLi} + E_{TFi} = (1+\delta_{PLi})U_{PLi} + (1+\delta_{TFi})U_{TFi}$$

$$E_{PLTFij} = \{[1+INC_{ij}]\,[E_{PLj} - E_{PLi}] + E_{PLi}\} +$$
$$+ \{[1+INC_{ij}]\,[E_{TFj} - E_{TFi}] + E_{TFi}\}$$

Plant and Tank Farm Depreciation

(15) $$DEP_{PLTFi} = DEP_{PLi} + DEP_{TFi}$$

$\left.\begin{matrix}(16)\\(17)\end{matrix}\right\}$, $$DEP_{PLTFi} = \frac{(1-\lambda_{PLi})E_{PLi}}{Y_{PLi}} + \frac{(1-\lambda_{TFi})E_{TFi}}{Y_{TFi}}$$

Plant Operating Cost

(6) $$C_{PLTFi} = H_{PLTFi} + CV_{PLTFi} + DEP_{PLTFi} +$$
$$+ E_{PLTFi}\,(\beta_{PLTFi} + \omega_{PLTFi}) + TAX_{PLTFi}$$

Table 76 (Continued). SUMMARY OF COST, REVENUE & PROFIT (CRP) MODEL EQUATIONS

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(7) $$H_{PLTFi} = CLA_{PLTFi} (1 + \Theta_{PLA})$$

(14) $$CV_{PLTFi} = CLP_{PLTFi} (1 + \Theta_{CLP}) + rX_1 (1 + \Theta_s [\alpha_{i1} f_{i1} + + \sum_{k=2}^{4} \alpha_k + \sum_{j=1}^{n} f_{ij} \epsilon_j]$$

(20) $$TAX_{PLTFi} = \eta(Land_{PLTFi} + E_{PLTFi})$$

Investment Capital

(24) $$I_i = I_{PLTFi} + I_{IST} + I_{TRAN} + SU_i$$

(2) $$I_{PLTFi} = Land_{PLTFi} + E_{PLTFi}$$

(25) $$SU_i = (C_{COL} + C_{DIST} + C_{PLTFi}) t_{SU}$$

Annual Cost of Investment Capital

(26) $$CI_i = (1-C_s) \rho_o \{ \frac{(E_{PLi} + SU_i)}{1-(1+\rho_o)^{-\gamma_{IST}}} + \frac{I_{TRAN}}{1-(1+\rho_o)^{-\gamma_{TRAN}}} + + \frac{E_{TFi} + Land_{PLTFi}}{1 - (1+\rho_o)^{-\gamma_{TFi}}} + \frac{I_{IST}}{1 - (1+\rho_o)^{-\gamma_{IST}}} \}$$

Table 76 (Continued). SUMMARY OF COST, REVENUE & PROFIT (CRP) MODEL EQUATIONS

Annual Cost of Operating Capital

(21) $$COC_i = [C_{COL} + C_{DIST} + C_{PLTFi}]\, t_f \rho_{oc}$$

Annual System Cost

(1) $$C_i = C_{PLTFi} + C_{COL} + C_{DIST} + COC_i + CI_i$$

Operating Revenue

(31) $$R_{si} = rX_1 \sum_j f_{ij} \overline{S}_j$$

Investment Revenue

(29) $$R_{Ii} = \frac{[DEP_{PLTFi} + DEP_{IST} + DEP_{TRAN}][(1+\rho_d)^{\gamma_{PLi}} - \rho_d \gamma_{PLi} - 1]}{\gamma_{PLi}\rho_d}$$

Other Revenue

(32) $$R_{oi} = q_1X_1 + q_2X_2 + X_1(1-r)\, S_r$$

Where: q_1X_1 = collection revenue
q_2X_2 = virgin oil tax revenue
$X_1(1-r)$ = incinerator revenue
S_r = incinerator charge ($/gal.)

Table 76 (Continued). SUMMARY OF COST, REVENUE & PROFIT (CRP) MODEL EQUATIONS

Annual System Revenue

$$R_i = R_{si} + R_{Ii} + R_{oi} \tag{28}$$

Annual Operating Profit

$$OP_i = R_{si} - [C_{PLTFi} + C_{COL} + C_{DIST} + COC_i] \tag{33}$$

Net Profit Before Taxes

$$NPBT_i = R_i - C_i \tag{34}$$

Cash Flow

$$CF_i = NPBT_i + DEP_{PLTFi} + DEP_{IST} + DEP_{TRAN} \tag{36}$$

Discounted Value of Cash Flow

$$\frac{CF_i}{I_i} = \frac{\rho^*}{[1-(1+\rho^*)^{-Y_{PLi}}} \tag{37}$$

Break Even Sales Price

$$\overline{S}^* = \frac{C_i - (R_{Oi} + R_{Ii})}{rf_iX_i} \tag{38}$$

APPENDIX L

SUMMARY

CASH FLOW, REVENUE, PROFIT (CRP)

Table 77. SUMMARY OF CASH FLOW, REVENUE & PROFIT (CRP)

BREAKEVEN PRICE PER GALLON OF PRODUCT PRODUCED

CASE I

TYPE OF PLANT Mechanical-Chemical Plant

SIZE OF PLANT 19,800,000 gallons per year

FINANCING 100% @ 7.25% interest rate

TAXES None

INCINERATORS 2

PRODUCT VALUE ($/gal) - Fuel Oil 0.122—Lube Stock 0.20—Cutter Stock 0.12

COLLECTION FEE ($/gal)	-0.02	0	+0.02
COST OF LAND ($)	653,400	653,400	653,400
PLANT - CONSTRUCTION COST ($)	5,700,000	5,700,000	5,700,000
DEPRECIATION ALLOWANCE ($/yr)	463,125	463,125	463,125
PLANT OPERATING COST ($/yr)	1,610,781	1,610,781	1,610,781
INVESTMENT CAPITAL REQUIRED ($)	7,539,636	7,539,636	7,539,636
COST OF INVESTMENT CAPITAL ($/yr)	972,562	972,562	972,562
COST OF OPERATING CAPITAL ($/yr)	28,000	28,000	28,000
ANNUAL SYSTEM COST ($/yr)	3,236,125	3,236,125	3,236,125
OPERATING REVENUE ($/yr)	1,848,622	1,848,622	1,848,622
INVESTMENT REVENUE ($/yr)	170,328	170,328	170,328
OTHER REVENUE ($/yr)	49,500	445,500	841,500
SYSTEM REVENUE ($/yr)	2,068,449	2,464,449	2,860,449
NET INCOME BEFORE TAXES ($/yr)	-1,167,676	-771,676	-375,676
CASH FLOW ($/yr)	-701,551	-305,551	90,449
BREAKEVEN AVERAGE SALES PRICE ($/gal)	0.20	0.18	0.15

Table 78. CRP MODEL - SYSTEM PARAMETERS FOR CASE I

PLANT INVESTMENT COST ($)	U_{PLi}	4050000.
TANK FARM INVESTMENT ($)	U_{TFi}	1650000.
PLANT - CONTINGENCY FACTOR	δ_{PLi}	0.0
TANK FARM CONTINGENCY FACTOR	δ_{TFi}	0.0
COST OF LAND ($/SQ FT)	Cl_{PLTFi}	1.00
PLANT SIZE (SQ FT)	A_{PLTFi}	653400.
SALVAGE VALUE FACTOR	λ_{PLi}	0.05
TANK FARM SALVAGE FACTOR	λ_{TFi}	0.05
SYSTEM LIFE (YEARS)	γ_{PLi}	10.
TANK FARM LIFE (YEARS)	γ_{TFi}	20.
ADMIN LABOR COST ($)	CLA_{PLTFi}	117106.
ADMIN LABOR OVERHEAD FACTOR	θ_{PLA}	0.450
PROD LABOR COST ($)	CLP_{PLTFi}	190894.
PROD LABOR OVERHEAD FACTOR	θ_{CLP}	0.45
START-UP PERIOD (YEARS)	t_{SU}	0.500
CAPITAL DEBT INT RATE	ρ_o	0.0725
OPERATING FLOAT (YEARS)	t_{OC}	0.167
INT ON OPN CAPITAL	ρ_ℓ	0.0750
YIELD OF MOTOR OIL	f_{i1}	0.0
YIELD OF FUEL OIL	f_{i2}	0.7674
YIELD OF CUTTER STOCK	f_{i3}	0.1694
YIELD OF LUBE OIL	f_{i4}	0.0326
DEMAND ACCT INT RATE	ρ_d	0.0675
TAX RATE (1/YEARS)	η	0.0
MAINTENANCE FACTOR (1/YEARS)	ω_{PLTFi}	0.02
INSURANCE FACTOR (1/YEARS)	β_{PLTFi}	0.0050
MOTOR OIL ADDITIVE FACTOR ($/GAL)	α_{i1}	0.1500
CUTTER STOCK FACTOR ($/GAL)	α_{i2}	0.0203
PROCESS FUEL FACTOR ($/GAL)	α_{i3}	0.0010
POWER FACTOR ($/GAL)	α_{i4}	0.0031
CHEMICAL FACTOR ($/GAL)	α_{i5}	0.0120
SUPPLY OVERHEAD FACTOR	θ_s	0.0
UNIT PRICE - MOTOR OIL	S_1	0.400
UNIT PRICE - FUEL OIL	S_2	0.122
UNIT PRICE - CUTTER STOCK	S_3	0.120
UNIT PRICE - LUBE OIL	S_4	0.200
CAPITALIZATION FACTOR	C_S	0.0
VOLUME WASTE OIL INPUT	X_1	19800000.
VOLUME VIRGIN TAXED (GALLONS)	X_2	0.
UNIT - COLLECTION FEE ($/GAL)	q_1	-0.020, 0.00, +0.02
UNIT - VIRGIN TAX ($/GAL)	q_2	0.0
WASTE RECOVERABLE FRACTION	r	0.775
UNIT INCINERATION PRICE ($/GAL)	S_r	0.100
INVESTMENT IN STORAGE ($)	I_{IST}	68455.
INVESTMENT IN TRUCKS ($)	I_{TRAN}	0.
LIFE OF STORAGE TANKS (YEARS)	γ_{IST}	20.
LIFE OF TRUCKS (YEARS)	γ_{TRAN}	5.
COLLECTION COST ($)	C_{COL}	593414.
DISTRIBUTION COST ($)	C_{DIST}	31368.
DEPRECIATION OF TANKS ($/YEAR)	DEP_{IST}	3000.
DEPRECIATION OF TRUCKS ($/YEAR)	DEP_{TRAN}	0.

Table 79. SUMMARY OF CASH FLOW, REVENUE & PROFIT (CRP)

BREAKEVEN PRICE PER GALLON OF PRODUCT PRODUCED

CASE II

TYPE OF PLANT Mechanical-Chemical Plant

SIZE OF PLANT 22,000,000 gallons per year

FINANCING 100% @ 6.53% interest rate

TAXES None

INCINERATORS 2 required

PRODUCT VALUE ($/gal) - Fuel Oil 0.15—Lube Stock 0.20—Cutter Stock 0.15

COLLECTION FEE ($/gal)

COST OF LAND ($)	65,400
PLANT - CONSTRUCTION COST ($)	4,560,000
DEPRECIATION ALLOWANCE ($/yr)	255,360
PLANT OPERATING COST ($/yr)	1,426,799
INVESTMENT CAPITAL REQUIRED ($)	5,418,765
COST OF INVESTMENT CAPITAL ($/yr)	541,918
COST OF OPERATING CAPITAL ($/yr)	9,687
ANNUAL SYSTEM COST ($/yr)	2,280,706
OPERATING REVENUE ($/yr)	2,673,775
INVESTMENT REVENUE ($/yr)	188,704
OTHER REVENUE ($/yr)	1,182,499
SYSTEM REVENUE ($/yr)	4,044,978
NET INCOME BEFORE TAXES ($/yr)	1,764,272
CASH FLOW ($/yr)	2,022,132
BREAKEVEN AVERAGE SALES PRICE ($/gal)	0.06

Table 80. CRP MODEL - SYSTEM PARAMETERS FOR CASE II

PLANT INVESTMENT COST ($)	U_{PLi}	4050000.
TANK FARM INVESTMENT ($)	U_{TFi}	1650000.
PLANT - CONTINGENCY FACTOR	δ_{PLi}	-0.20
TANK FARM CONTINGENCY FACTOR	δ_{TFi}	-0.20
COST OF LAND ($/SQ FT)	Cl_{PLTFi}	0.10
PLANT SIZE (SQ FT)	A_{PLTFi}	653400.
SALVAGE VALUE FACTOR	λ_{PLi}	0.05
TANK FARM SALVAGE FACTOR	λ_{TFi}	0.05
SYSTEM LIFE (YEARS)	γ_{PLi}	15.
TANK FARM LIFE (YEARS)	γ_{TFi}	25.
ADMIN LABOR COST ($)	CLA_{PLTFi}	99540.
ADMIN LABOR OVERHEAD FACTOR	θ_{PLA}	0.405
PROD LABOR COST ($)	CLP_{PLTFi}	171804.
PROD LABOR OVERHEAD FACTOR	θ_{CLP}	0.40
START-UP PERIOD (YEARS)	t_{SU}	0.417
CAPITAL DEBT INT RATE	ρ_o	0.0653
OPERATING FLOAT (YEARS)	t_{OC}	0.083
INT ON OPN CAPITAL	ρ_ℓ	0.0675
YIELD OF MOTOR OIL	f_{i1}	0.0326
YIELD OF FUEL OIL	f_{i2}	0.7674
YIELD OF CUTTER STOCK	f_{i3}	0.1694
YIELD OF LUBE OIL	f_{i4}	0.0
DEMAND ACCT INT RATE	ρ_d	0.0743
TAX RATE (1/YEARS)	η	0.0
MAINTENANCE FACTOR (1/YEARS)	ω_{PLTFi}	0.02
INSURANCE FACTOR (1/YEARS)	β_{PLTFi}	0.0050
MOTOR OIL ADDITIVE FACTOR ($/GAL)	α_{i1}	0.1000
CUTTER STOCK FACTOR ($/GAL)	α_{i2}	0.0203
PROCESS FUEL FACTOR ($/GAL)	α_{i3}	0.0010
POWER FACTOR ($/GAL)	α_{i4}	0.0031
CHEMICAL FACTOR ($/GAL)	α_{i5}	0.0120
SUPPLY OVERHEAD FACTOR	θ_s	0.0
UNIT PRICE - MOTOR OIL	S_1	0.500
UNIT PRICE - FUEL OIL	S_2	0.150
UNIT PRICE - CUTTER STOCK	S_3	0.150
UNIT PRICE - LUBE OIL	S_4	0.200
CAPITALIZATION FACTOR	C_S	0.0
VOLUME WASTE OIL INPUT	X_1	22000000.
VOLUME VIRGIN TAXED (GALLONS)	X_2	0.
UNIT - COLLECTION FEE ($/GAL)	q_1	0.020
UNIT - VIRGIN TAX ($/GAL	q_2	0.0
WASTE RECOVERABLE FRACTION	r	0.775
UNIT INCINERATION PRICE ($/GAL)	S_r	0.150
INVESTMENT IN STORAGE ($)	I_{IST}	72391.
INVESTMENT IN TRUCKS ($)	I_{TRAN}	0.
LIFE OF STORAGE TANKS (YEARS)	γ_{IST}	25.
LIFE OF TRUCKS (YEARS)	γ_{TRAN}	7.
COLLECTION COST ($)	C_{COL}	278922.
DISTRIBUTION COST ($)	C_{DIST}	23380.
DEPRECIATION OF TANKS ($/YEAR)	DEP_{IST}	2500.
DEPRECIATION OF TRUCKS ($/YEAR)	DEP_{TRAN}	0.

Table 81. SUMMARY OF CASH FLOW, REVENUE & PROFIT (CRP)

BREAKEVEN PRICE PER GALLON OF PRODUCT PRODUCED

CASE III

TYPE OF PLANT Mechanical-Chemical Plant

SIZE OF PLANT 18,000,000 gallons per year

FINANCING 100% @ 7.98% interest rate

TAXES None

INCINERATORS 2 required

PRODUCT VALUE ($/gal) - Fuel Oil 0.10—Lube Stock 0.20—Cutter Stock 0.12

COLLECTION FEE ($/gal)

COST OF LAND ($)	1,306,800
PLANT - CONSTRUCTION COST ($)	6,839,998
DEPRECIATION ALLOWANCE ($/yr)	1,048,799
PLANT OPERATING COST ($/yr)	2,384,910
INVESTMENT CAPITAL REQUIRED ($)	10,527,703
COST OF INVESTMENT CAPITAL ($/yr)	2,184,111
COST OF OPERATING CAPITAL ($/yr)	81,055
ANNUAL SYSTEM COST ($/yr)	6,195,118
OPERATING REVENUE ($/yr)	1,513,266
INVESTMENT REVENUE ($/yr)	136,226
OTHER REVENUE ($/yr)	-360,000
SYSTEM REVENUE ($/yr)	1,289,492
NET INCOME BEFORE TAXES ($/yr)	-4,905,626
CASH FLOW ($/yr)	-3,851,327
BREAKEVEN AVERAGE SALES PRICE ($/gal)	0.47

Table 82. CRP MODEL - SYSTEM PARAMETERS FOR CASE III

PLANT INVESTMENT COST ($)	U_{PLi}	4050000.
TANK FARM INVESTMENT ($)	U_{TFi}	1650000.
PLANT - CONTINGENCY FACTOR	δ_{PLi}	0.20
TANK FARM CONTINGENCY FACTOR	δ_{TFi}	0.20
COST OF LAND ($/SQ FT)	Cl_{PLTFi}	2.00
PLANT SIZE (SQ FT)	A_{PLTFi}	653400.
SALVAGE VALUE FACTOR	λ_{PLi}	0.05
TANK FARM SALVAGE FACTOR	λ_{TFi}	0.05
SYSTEM LIFE (YEARS)	Y_{PLi}	5.
TANK FARM LIFE (YEARS)	Y_{TFi}	15.
ADMIN LABOR COST ($)	CLA_{PLTFi}	128817.
ADMIN LABOR OVERHEAD FACTOR	θ_{PLA}	0.495
PROD LABOR COST ($)	CLP_{PLTFi}	209983.
PROD LABOR OVERHEAD FACTOR	θ_{CLP}	0.49
START-UP PERIOD (YEARS)	t_{SU}	0.583
CAPITAL DEBT INT RATE	ρ_o	0.0798
OPERATING FLOAT (YEARS)	t_{OC}	0.250
INT ON OPN CAPITAL	ρ_ℓ	0.0825
YIELD OF MOTOR OIL	f_{i1}	0.0326
YIELD OF FUEL OIL	f_{i2}	0.7674
YIELD OF CUTTER STOCK	f_{i3}	0.1694
YIELD OF LUBE OIL	f_{i4}	0.0
DEMAND ACCT INT RATE	ρ_d	0.0608
TAX RATE (1/YEARS)	η	0.0
MAINTENANCE FACTOR (1/YEARS)	ω_{PLTFi}	0.02
INSURANCE FACTOR (1/YEARS)	β_{PLTFi}	0.0050
MOTOR OIL ADDITIVE FACTOR ($/GAL)	α_{i1}	0.2000
CUTTER STOCK FACTOR ($/GAL)	α_{i2}	0.0203
PROCESS FUEL FACTOR ($/GAL)	α_{i3}	0.0010
POWER FACTOR ($/GAL)	α_{i4}	0.0031
CHEMICAL FACTOR ($/GAL)	α_{i5}	0.0120
SUPPLY OVERHEAD FACTOR	θ_s	0.10
UNIT PRICE - MOTOR OIL	S_1	0.350
UNIT PRICE - FUEL OIL	S_2	0.100
UNIT PRICE - CUTTER STOCK	S_3	0.120
UNIT PRICE - LUBE OIL	S_4	0.200
CAPITALIZATION FACTOR	C_S	0.0
VOLUME WASTE OIL INPUT	X_1	18000000.
VOLUME VIRGIN TAXED (GALLONS)	X_2	0.
UNIT - COLLECTION FEE ($/GAL)	q_1	-0.020
UNIT - VIRGIN TAX ($/GAL)	q_2	0.0
WASTE RECOVERABLE FRACTION	r	0.775
UNIT INCINERATION PRICE ($/GAL)	S_r	0.0
INVESTMENT IN STORAGE ($)	I_{IST}	89744.
INVESTMENT IN TRUCKS ($)	I_{TRAN}	0.
LIFE OF STORAGE TANKS (YEARS)	Y_{IST}	15.
LIFE OF TRUCKS (YEARS)	Y_{TRAN}	3.
COLLECTION COST ($)	C_{COL}	1373928.
DISTRIBUTION COST ($)	C_{DIST}	171114.
DEPRECIATION OF TANKS ($/YEAR)	DEP_{IST}	5500.
DEPRECIATION OF TRUCKS ($/YEAR)	DEP_{TRAN}	0.

Table 83. SUMMARY OF CASH FLOW, REVENUE & PROFIT (CRP)

BREAKEVEN PRICE PER GALLON OF PRODUCT PRODUCED

CASE IV

TYPE OF PLANT Mechanical-Chemical Plant

SIZE OF PLANT 19,800,000 gallons per year

FINANCING 100% capitalization @ 0.0% interest rate

TAXES None

INCINERATORS 2 required

PRODUCT VALUE ($/gal) - Fuel Oil 0.122—Lube Stock 0.20—Cutter Stock 0.12

COLLECTION FEE ($/gal)	-0.02	0	+0.02
COST OF LAND ($)	65,340	65,340	65,340
PLANT - CONSTRUCTION COST ($)	57,000,000	5,700,000	5,700,000
DEPRECIATION ALLOWANCE ($/yr)	463,125	463,125	463,125
PLANT OPERATING COST ($/yr)	1,610,781	1,610,781	1,610,781
INVESTMENT CAPITAL REQUIRED ($)	7,539,636	7,539,636	7,539,636
COST OF INVESTMENT CAPITAL ($/yr)	0.0	0.0	0.0
COST OF OPERATING CAPITAL ($/yr)	28,000	28,000	28,000
ANNUAL SYSTEM COST ($/yr)	2,263,563	2,263,563	2,263,563
OPERATING REVENUE ($/yr)	1,848,622	1,848,622	1,848,622
INVESTMENT REVENUE ($/yr)	170,328	170,328	170,328
OTHER REVENUE ($/yr)	49,500	445,500	841,500
SYSTEM REVENUE ($/yr)	2,068,449	2,464,449	2,860,449
NET INCOME BEFORE TAXES ($/yr)	-195,114	200,886	596,886
CASH FLOW ($/yr)	271,011	667,011	1,063,011
BREAKEVEN AVERAGE SALES PRICE ($/gal)	0.14	0.11	0.08

Table 84. CRP MODEL - SYSTEM PARAMETERS FOR CASE IV

PLANT INVESTMENT COST ($)	U_{PLi}	4050000.
TANK FARM INVESTMENT ($)	U_{TFi}	1650000.
PLANT - CONTINGENCY FACTOR	δ_{PLi}	0.0
TANK FARM CONTINGENCY FACTOR	δ_{TFi}	0.0
COST OF LAND ($/SQ FT)	Cl_{PLTFi}	1.00
PLANT SIZE (SQ FT)	A_{PLTFi}	653400.
SALVAGE VALUE FACTOR	λ_{PLi}	0.05
TANK FARM SALVAGE FACTOR	λ_{TFi}	0.05
SYSTEM LIFE (YEARS)	Y_{PLi}	10.
TANK FARM LIFE (YEARS)	Y_{TFi}	20.
ADMIN LABOR COST ($)	CLA_{PLTFi}	117106.
ADMIN LABOR OVERHEAD FACTOR	θ_{PLA}	0.450
PROD LABOR COST ($)	CLP_{PLTFi}	190894.
PROD LABOR OVERHEAD FACTOR	θ_{CLP}	0.45
START-UP PERIOD (YEARS)	t_{SU}	0.500
CAPITAL DEBT INT RATE	ρ_o	0.0725
OPERATING FLOAT (YEARS)	t_{OC}	0.167
INT ON OPN CAPITAL	ρ_ℓ	0.0750
YIELD OF MOTOR OIL	f_{i1}	0.0
YIELD OF FUEL OIL	f_{i2}	0.7674
YIELD OF CUTTER STOCK	f_{i3}	0.1694
YIELD OF LUBE OIL	f_{i4}	0.0326
DEMAND ACCT INT RATE	ρ_d	0.0675
TAX RATE (1/YEARS)	η	0.0
MAINTENANCE FACTOR (1/YEARS)	ω_{PLTFi}	0.02
INSURANCE FACTOR (1/YEARS)	β_{PLTFi}	0.0050
MOTOR OIL ADDITIVE FACTOR ($/GAL)	α_{i1}	0.1500
CUTTER STOCK FACTOR ($/GAL)	α_{i2}	0.0203
PROCESS FUEL FACTOR ($/GAL)	α_{i3}	0.0010
POWER FACTOR ($/GAL)	α_{i4}	0.0031
CHEMICAL FACTOR ($/GAL)	α_{i5}	0.0120
SUPPLY OVERHEAD FACTOR	θ_s	0.0
UNIT PRICE - MOTOR OIL	S_1	0.400
UNIT PRICE - FUEL OIL	S_2	0.122
UNIT PRICE - CUTTER STOCK	S_3	0.120
UNIT PRICE - LUBE OIL	S_4	0.200
CAPITALIZATION FACTOR	C_S	1.00
VOLUME WASTE OIL INPUT	X_1	19800000.
VOLUME VIRGIN TAXED (GALLONS)	X_2	0.
UNIT - COLLECTION FEE ($/GAL)	q_1	-0.020, 0.00, +0.02
UNIT - VIRGIN TAX ($/GAL)	q_2	0.0
WASTE RECOVERABLE FRACTION	r	0.775
UNIT INCINERATION PRICE ($/GAL)	S_r	0.100
INVESTMENT IN STORAGE ($)	I_{IST}	68455.
INVESTMENT IN TRUCKS ($)	I_{TRAN}	0.
LIFE OF STORAGE TANKS (YEARS)	Y_{IST}	20.
LIFE OF TRUCKS (YEARS)	Y_{TRAN}	5.
COLLECTION COST ($)	C_{COL}	593414.
DISTRIBUTION COST ($)	C_{DIST}	31368.
DEPRECIATION OF TANKS ($/YEAR)	DEP_{IST}	3000.
DEPRECIATION OF TRUCKS ($/YEAR)	DEP_{TRAN}	0.

Table 85. SUMMARY OF CASH FLOW, REVENUE & PROFIT (CRP)

BREAKEVEN PRICE PER GALLON OF PRODUCT PRODUCED

CASE V

TYPE OF PLANT Mechanical-Chemical Plant

SIZE OF PLANT 19,800,000 gallons per year

FINANCING 100% @ 7.25% interest rate

TAXES None

INCINERATORS Bottoms Sold -- 1 incinerator required

PRODUCT VALUE ($/gal) - Fuel Oil 0.112—Lube Stock 0.20—Cutter Stock 0.12

COLLECTION FEE ($/gal)	-0.02	0	+0.02
COST OF LAND ($)	653,400	653,400	653,400
PLANT - CONSTRUCTION COST ($)	5,400,000	5,400,000	5,400,000
DEPRECIATION ALLOWANCE ($/yr)	434,625	434,625	434,625
PLANT OPERATING COST ($/yr)	1,554,436	1,554,436	1,554,436
INVESTMENT CAPITAL REQUIRED ($)	7,213,964	7,213,964	7,213,964
COST OF INVESTMENT CAPITAL ($/yr)	925,656	925,656	925,656
COST OF OPERATING CAPITAL ($/yr)	27,357	27,357	27,357
ANNUAL SYSTEM COST ($/yr)	3,137,231	3,137,231	3,137,231
OPERATING REVENUE ($/yr)	1,848,622	1,848,622	1,848,622
INVESTMENT REVENUE ($/yr)	159,914	159,914	159,914
OTHER REVENUE ($/yr)	49,500	445,500	841,500
SYSTEM REVENUE ($/yr)	2,058,035	2,454,035	2,850,035
NET INCOME BEFORE TAXES ($/yr)	-1,079,196	-683,196	-287,496
CASH FLOW ($/yr)	-641,571	-245,571	150,429
BREAKEVEN AVERAGE SALES PRICE ($/gal)	0.20	0.17	0.14

PLANT INVESTMENT COST ($)	U_{PLi}	3750000.
TANK FARM INVESTMENT ($)	U_{TFi}	1650000.
PLANT - CONTINGENCY FACTOR	δ_{PLi}	0.0
TANK FARM CONTINGENCY FACTOR	δ_{TFi}	0.0
COST OF LAND ($/SQ FT)	Cl_{PLTFi}	1.00
PLANT SIZE (SQ FT)	A_{PLTFi}	653400.
SALVAGE VALUE FACTOR	λ_{PLi}	0.05
TANK FARM SALVAGE FACTOR	λ_{TFi}	0.05
SYSTEM LIFE (YEARS)	γ_{PLi}	10.
TANK FARM LIFE (YEARS)	γ_{TFi}	20.
ADMIN LABOR COST ($)	CLA_{PLTFi}	117106.
ADMIN LABOR OVERHEAD FACTOR	θ_{PLA}	0.450
PROD LABOR COST ($)	CLP_{PLTFi}	190894.
PROD LABOR OVERHEAD FACTOR	θ_{CLP}	0.45
START-UP PERIOD (YEARS)	t_{SU}	0.500
CAPITAL DEBT INT RATE	ρ_o	0.0725
OPERATING FLOAT (YEARS)	t_{OC}	0.167
INT ON OPN CAPITAL	ρ_ℓ	0.0750
YIELD OF MOTOR OIL	f_{i1}	0.0
YIELD OF FUEL OIL	f_{i2}	0.7674
YIELD OF CUTTER STOCK	f_{i3}	0.1694
YIELD OF LUBE OIL	f_{i4}	0.0326
DEMAND ACCT INT RATE	ρ_d	0.0675
TAX RATE (1/YEARS)	η	0.0
MAINTENANCE FACTOR (1/YEARS)	ω_{PLTFi}	0.02
INSURANCE FACTOR (1/YEARS)	β_{PLTFi}	0.0050
MOTOR OIL ADDITIVE FACTOR ($/GAL)	α_{i1}	0.1500
CUTTER STOCK FACTOR ($/GAL)	α_{i2}	0.0203
PROCESS FUEL FACTOR ($/GAL)	α_{i3}	0.0010
POWER FACTOR ($/GAL)	α_{i4}	0.0021
CHEMICAL FACTOR ($/GAL)	α_{i5}	0.0120
SUPPLY OVERHEAD FACTOR	θ_s	0.0
UNIT PRICE - MOTOR OIL	S_1	0.400
UNIT PRICE - FUEL OIL	S_2	0.122
UNIT PRICE - CUTTER STOCK	S_3	0.120
UNIT PRICE - LUBE OIL	S_4	0.200
CAPITALIZATION FACTOR	C_S	0.0
VOLUME WASTE OIL INPUT	X_1	19800000.
VOLUME VIRGIN TAXED (GALLONS)	X_2	0.
UNIT - COLLECTION FEE ($/GAL)	q_1	-0.020, 0.00, +0.02
UNIT - VIRGIN TAX ($/GAL)	q_2	0.0
WASTE RECOVERABLE FRACTION	r	0.775
UNIT INCINERATION PRICE ($/GAL)	S_r	0.100
INVESTMENT IN STORAGE ($)	I_{IST}	68455.
INVESTMENT IN TRUCKS ($)	I_{TRAN}	0.
LIFE OF STORAGE TANKS (YEARS)	γ_{IST}	20.
LIFE OF TRUCKS (YEARS)	γ_{TRAN}	5.
COLLECTION COST ($)	C_{COL}	593414.
DISTRIBUTION COST ($)	C_{DIST}	31368.
DEPRECIATION OF TANKS ($/YEAR)	DEP_{IST}	3000.
DEPRECIATION OF TRUCKS ($/YEAR)	DEP_{TRAN}	0.

Table 87. SUMMARY OF CASH FLOW, REVENUE & PROFIT (CRP)

BREAKEVEN PRICE PER GALLON OF PRODUCT PRODUCED

CASE VI

TYPE OF PLANT Vacuum Distillation and Hydrofining

SIZE OF PLANT 30,000,000 gallons per year

FINANCING 100% @ 7.25% interest rate

TAXES 0.0122

INCINERATORS Bottoms Sold -- 1 incinerator required

PRODUCT VALUE ($/gal) - Fuel Oil 0.122—Lube Stock 0.20—Cutter Stock 0.15

COLLECTION FEE ($/gal)	-0.02	0	+0.02
COST OF LAND ($)	653,400	653,400	653,400
PLANT - CONSTRUCTION COST ($)	5,700,000	5,700,000	5,700,000
DEPRECIATION ALLOWANCE ($/yr)	463,125	463,125	463,125
PLANT OPERATING COST ($/yr)	1,794,919	1,794,191	1,794,191
INVESTMENT CAPITAL REQUIRED ($)	7,635,461	7,635,461	7,635,461
COST OF INVESTMENT CAPITAL ($/yr)	986,364	986,364	986,364
COST OF OPERATING CAPITAL ($/yr)	30,400	30,400	30,400
ANNUAL SYSTEM COST ($/yr)	3,443,977	3,443,977	3,443,977
OPERATING REVENUE ($/yr)	3,154,187	3,154,187	3,154,187
INVESTMENT REVENUE ($/yr)	170,328	170,328	170,328
OTHER REVENUE ($/yr)	129,000	729,000	1,328,999
SYSTEM REVENUE ($/yr)	3,453,514	4,053,514	4,653,514
NET INCOME BEFORE TAXES ($/yr)	9,537	696,574	1,209,537
CASH FLOW ($/yr)	475,662	1,075,662	1,675,662
BREAKEVEN AVERAGE SALES PRICE ($/gal)	0.16	0.13	0.10

Table 88. CRP MODEL - SYSTEM PARAMETERS FOR CASE VI

PLANT INVESTMENT COST ($)	U_{PLi}	4050000.
TANK FARM INVESTMENT ($)	U_{TFi}	1650000.
PLANT - CONTINGENCY FACTOR	δ_{PLi}	0.0
TANK FARM CONTINGENCY FACTOR	δ_{TFi}	0.0
COST OF LAND ($/SQ FT)	Cl_{PLTFi}	1.00
PLANT SIZE (SQ FT)	A_{PLTFi}	653400.
SALVAGE VALUE FACTOR	λ_{PLi}	0.05
TANK FARM SALVAGE FACTOR	λ_{TFi}	0.05
SYSTEM LIFE (YEARS)	Y_{PLi}	10.
TANK FARM LIFE (YEARS)	Y_{TFi}	20.
ADMIN LABOR COST ($)	CLA_{PLTFi}	117106.
ADMIN LABOR OVERHEAD FACTOR	θ_{PLA}	0.450
PROD LABOR COST ($)	CLP_{PLTFi}	118381.
PROD LABOR OVERHEAD FACTOR	θ_{CLP}	0.45
START-UP PERIOD (YEARS)	t_{SU}	0.500
CAPITAL DEBT INT RATE	ρ_{o}	0.0725
OPERATING FLOAT (YEARS)	t_{OC}	0.167
INT ON OPN CAPITAL	ρ_{ℓ}	0.0750
YIELD OF MOTOR OIL	f_{i1}	0.0
YIELD OF FUEL OIL	f_{i2}	0.3350
YIELD OF CUTTER STOCK	f_{i3}	0.2068
YIELD OF LUBE OIL	f_{i4}	0.3350
DEMAND ACCT INT RATE	ρ_{d}	0.0675
TAX RATE (1/YEARS)	η	0.0112
MAINTENANCE FACTOR (1/YEARS)	ω_{PLTFi}	0.02
INSURANCE FACTOR (1/YEARS)	β_{PLTFi}	0.0050
MOTOR OIL ADDITIVE FACTOR ($/GAL)	α_{i1}	0.1500
CUTTER STOCK FACTOR ($/GAL)	α_{i2}	0.0248
PROCESS FUEL FACTOR ($/GAL)	α_{i3}	0.0010
POWER FACTOR ($/GAL)	α_{i4}	0.0015
CHEMICAL FACTOR ($/GAL)	α_{i5}	0.0069
SUPPLY OVERHEAD FACTOR	θ_{s}	0.0
UNIT PRICE - MOTOR OIL	S_1	0.400
UNIT PRICE - FUEL OIL	S_2	0.122
UNIT PRICE - CUTTER STOCK	S_3	0.150
UNIT PRICE - LUBE OIL	S_4	0.200
CAPITALIZATION FACTOR	C_S	0.0
VOLUME WASTE OIL INPUT	X_1	30000000.
VOLUME VIRGIN TAXED (GALLONS)	X_2	0.
UNIT - COLLECTION FEE ($/GAL)	q_1	-0.020, 0.00, +0.02
UNIT - VIRGIN TAX ($/GAL)	q_2	0.0
WASTE RECOVERABLE FRACTION	r	0.757
UNIT INCINERATION PRICE ($/GAL)	S_r	0.100
INVESTMENT IN STORAGE ($)	I_{IST}	68455.
INVESTMENT IN TRUCKS ($)	I_{TRAN}	0.
LIFE OF STORAGE TANKS (YEARS)	Y_{IST}	20.
LIFE OF TRUCKS (YEARS)	Y_{TRAN}	5.
COLLECTION COST ($)	C_{COL}	593414.
DISTRIBUTION COST ($)	C_{DIST}	38880.
DEPRECIATION OF TANKS ($/YEAR)	DEP_{IST}	3000.
DEPRECIATION OF TRUCKS ($/YEAR)	DEP_{TRAN}	0.

Table 89. SUMMARY OF CASH FLOW, REVENUE & PROFIT (CRP)

BREAKEVEN PRICE PER GALLON OF PRODUCT PRODUCED

CASE VII

TYPE OF PLANT Mechanical Chemical Plant

SIZE OF PLANT 30,000,000 gallons per year

FINANCING 100% @ 7.25% interest rate

TAXES 0.0112

INCINERATORS 2 required

PRODUCT VALUE ($/gal) - Fuel Oil 0.122—Lube Stock 0.20—Cutter Stock 0.12

COLLECTION FEE ($/gal)	-0.02	0	+0.02
COST OF LAND ($)	653,400	653,400	653,400
PLANT - CONSTRUCTION COST ($)	6,585,000	6,585,000	6,585,000
DEPRECIATION ALLOWANCE ($/yr)	539,362	539,362	539,362
PLANT OPERATING COST ($/yr)	2,157,394	2,157,394	2,157,394
INVESTMENT CAPITAL REQUIRED ($)	8,709,749	8,709,749	8,709,749
COST OF INVESTMENT CAPITAL ($/yr)	1,133,206	1,133,206	1,133,206
COST OF OPERATING CAPITAL ($/yr)	35,142	35,142	35,142
ANNUAL SYSTEM COST ($/yr)	3,974,137	3,974,137	3,974,137
OPERATING REVENUE ($/yr)	3,197,321	3,197,321	3,197,321
INVESTMENT REVENUE ($/yr)	198,187	198,187	198,187
OTHER REVENUE ($/yr)	-102,000	498,000	1,098,000
SYSTEM REVENUE ($/yr)	3,293,506	3,893,506	4,493,506
NET INCOME BEFORE TAXES ($/yr)	-680,631	-80,631	519,369
CASH FLOW ($/yr)	-138,268	461,731	1,061,731
BREAKEVEN AVERAGE SALES PRICE ($/gal)	-.15	-.13	0.10

Table 90. CRP MODEL - SYSTEM PARAMETERS FOR CASE VII

PLANT INVESTMENT COST ($)	U_{PLi}	4770000.
TANK FARM INVESTMENT ($)	U_{TFi}	1815000.
PLANT - CONTINGENCY FACTOR	δ_{PLi}	0.0
TANK FARM CONTINGENCY FACTOR	δ_{TFi}	0.0
COST OF LAND ($/SQ FT)	$C1_{PLTFi}$	1.00
PLANT SIZE (SQ FT)	A_{PLTFi}	653400.
SALVAGE VALUE FACTOR	λ_{PLi}	0.05
TANK FARM SALVAGE FACTOR	λ_{TFi}	0.05
SYSTEM LIFE (YEARS)	Y_{PLi}	10.
TANK FARM LIFE (YEARS)	Y_{TFi}	20.
ADMIN LABOR COST ($)	CLA_{PLTFi}	117106.
ADMIN LABOR OVERHEAD FACTOR	θ_{PLA}	0.450
PROD LABOR COST ($)	CLP_{PLTFi}	190894.
PROD LABOR OVERHEAD FACTOR	θ_{CLP}	0.45
START-UP PERIOD (YEARS)	t_{SU}	0.500
CAPITAL DEBT INT RATE	ρ_o	0.0725
OPERATING FLOAT (YEARS)	t_{OC}	0.167
INT ON OPN CAPITAL	ρ_ℓ	0.0750
YIELD OF MOTOR OIL	f_{i1}	0.0
YIELD OF FUEL OIL	f_{i2}	0.8274
YIELD OF CUTTER STOCK	f_{i3}	0.1694
YIELD OF LUBE OIL	f_{i4}	0.0326
DEMAND ACCT INT RATE	ρ_d	0.0675
TAX RATE (1/YEARS)	η	0.112
MAINTENANCE FACTOR (1/YEARS)	ω_{PLTFi}	0.02
INSURANCE FACTOR (1/YEARS)	β_{PLTFi}	0.0050
MOTOR OIL ADDITIVE FACTOR ($/GAL)	α_{i1}	0.1500
CUTTER STOCK FACTOR ($/GAL)	α_{i2}	0.0219
PROCESS FUEL FACTOR ($/GAL)	α_{i3}	0.0010
POWER FACTOR ($/GAL)	α_{i4}	0.0021
CHEMICAL FACTOR ($/GAL)	α_{i5}	0.0120
SUPPLY OVERHEAD FACTOR	θ_s	0.0
UNIT PRICE - MOTOR OIL	S_1	0.400
UNIT PRICE - FUEL OIL	S_2	0.122
UNIT PRICE - CUTTER STOCK	S_3	0.120
UNIT PRICE - LUBE OIL	S_4	0.200
CAPITALIZATION FACTOR	C_S	0.0
VOLUME WASTE OIL INPUT	X_1	30000000.
VOLUME VIRGIN TAXED (GALLONS)	X_2	0.
UNIT - COLLECTION FEE ($/GAL)	q_1	-0.020, 0.00, +0.02
UNIT - VIRGIN TAX ($/GAL)	q_2	0.0
WASTE RECOVERABLE FRACTION	r	0.834
UNIT INCINERATION PRICE ($/GAL)	S_r	0.100
INVESTMENT IN STORAGE ($)	I_{IST}	68455.
INVESTMENT IN TRUCKS ($)	I_{TRAN}	0.
LIFE OF STORAGE TANKS (YEARS)	Y_{IST}	20.
LIFE OF TRUCKS (YEARS)	Y_{TRAN}	5.
COLLECTION COST ($)	C_{COL}	593414.
DISTRIBUTION COST ($)	C_{DIST}	54981.
DEPRECIATION OF TANKS ($/YEAR)	DEP_{IST}	3000.
DEPRECIATION OF TRUCKS ($/YEAR)	DEP_{TRAN}	0.

Table 91. SUMMARY OF CASH FLOW, REVENUE & PROFIT (CRP)

BREAKEVEN PRICE PER GALLON OF PRODUCT PRODUCED

CASE VIII

TYPE OF PLANT Mechanical-Chemical Plant

SIZE OF PLANT 30,000,000 gallons per year

FINANCING 100% @ 7.25% interest rate

TAXES 0.0112

INCINERATORS 2 required

PRODUCT VALUE ($/gal) - Fuel Oil 0.15—Lube Stock 0.25—Cutter Stock 0.15

COLLECTION FEE ($/gal)	-0.02	0	+0.02
COST OF LAND ($)	653,400	653,400	653,400
PLANT - CONSTRUCTION COST ($)	6,585,000	6,585,000	6,585,000
DEPRECIATION ALLOWANCE ($/yr)	539,362	539,362	539,362
PLANT OPERATING COST ($/yr)	2,292,502	2,292,502	2,292,502
INVESTMENT CAPITAL REQUIRED ($)	8,777,303	8,777,303	8,777,303
COST OF INVESTMENT CAPITAL ($/yr)	1,142,936	1,142,936	1,142,936
COST OF OPERATING CAPITAL ($/yr)	36,835	36,835	36,835
ANNUAL SYSTEM COST ($/yr)	4,120,667	4,120,667	4,120,667
OPERATING REVENUE ($/yr)	3,944,896	3,944,896	3,944,896
INVESTMENT REVENUE ($/yr)	198,187	198,187	198,187
OTHER REVENUE ($/yr)	-102,000	498,000	1,098,000
SYSTEM REVENUE ($/yr)	4,041,081	4,641,081	5,241,081
NET INCOME BEFORE TAXES ($/yr)	-79,586	520,414	1,120,414
CASH FLOW ($/yr)	462,776	1,062,776	1,662,776
BREAKEVEN AVERAGE SALES PRICE ($/gal)	0.16	0.13	0.11

Table 92. CRP MODEL - SYSTEM PARAMETERS FOR CASE VIII

PLANT INVESTMENT COST ($)	U_{PLi}	4770000.
TANK FARM INVESTMENT ($)	U_{TFi}	1815000.
PLANT - CONTINGENCY FACTOR	δ_{PLi}	0.0
TANK FARM CONTINGENCY FACTOR	δ_{TFi}	0.0
COST OF LAND ($/SQ FT)	Cl_{PLTFi}	1.00
PLANT SIZE (SQ FT)	A_{PLTFi}	653400.
SALVAGE VALUE FACTOR	λ_{PLi}	0.05
TANK FARM SALVAGE FACTOR	λ_{TFi}	0.05
SYSTEM LIFE (YEARS)	Y_{PLi}	10.
TANK FARM LIFE (YEARS)	Y_{TFi}	20.
ADMIN LABOR COST ($)	CLA_{PLTFi}	117106.
ADMIN LABOR OVERHEAD FACTOR	θ_{PLA}	0.450
PROD LABOR COST ($)	CLP_{PLTFi}	190894.
PROD LABOR OVERHEAD FACTOR	θ_{CLP}	0.45
START-UP PERIOD (YEARS)	t_{SU}	0.500
CAPITAL DEBT INT RATE	ρ_o	0.0725
OPERATING FLOAT (YEARS)	t_{OC}	0.167
INT ON OPN CAPITAL	ρ_ℓ	0.0750
YIELD OF MOTOR OIL	f_{i1}	0.0
YIELD OF FUEL OIL	f_{i2}	0.8274
YIELD OF CUTTER STOCK	f_{i3}	0.1694
YIELD OF LUBE OIL	f_{i4}	0.0326
DEMAND ACCT INT RATE	ρ_d	0.0675
TAX RATE (1/YEARS)	η	0.0112
MAINTENANCE FACTOR (1/YEARS)	ω_{PLTFi}	0.02
INSURANCE FACTOR (1/YEARS)	β_{PLTFi}	0.0050
MOTOR OIL ADDITIVE FACTOR ($/GAL)	α_{i1}	0.1500
CUTTER STOCK FACTOR ($/GAL)	α_{i2}	0.0273
PROCESS FUEL FACTOR ($/GAL)	α_{i3}	0.0010
POWER FACTOR ($/GAL)	α_{i4}	0.0021
CHEMICAL FACTOR ($/GAL)	α_{i5}	0.0120
SUPPLY OVERHEAD FACTOR	θ_s	0.0
UNIT PRICE - MOTOR OIL	S_1	0.400
UNIT PRICE - FUEL OIL	S_2	0.150
UNIT PRICE - CUTTER STOCK	S_3	0.150
UNIT PRICE - LUBE OIL	S_4	0.250
CAPITALIZATION FACTOR	C_S	0.0
VOLUME WASTE OIL INPUT	X_1	30000000.
VOLUME VIRGIN TAXED (GALLONS)	X_2	0.
UNIT - COLLECTION FEE ($/GAL)	q_1	-0.020, 0.00, +0.02
UNIT - VIRGIN TAX ($/GAL)	q_2	0.0
WASTE RECOVERABLE FRACTION	r	0.834
UNIT INCINERATION PRICE ($/GAL)	S_r	0.100
INVESTMENT IN STORAGE ($)	I_{IST}	68455.
INVESTMENT IN TRUCKS ($)	I_{TRAN}	0.
LIFE OF STORAGE TANKS (YEARS)	Y_{IST}	20.
LIFE OF TRUCKS (YEARS)	Y_{TRAN}	5.
COLLECTION COST ($)	C_{COL}	593414.
DISTRIBUTION COST ($)	C_{DIST}	54981.
DEPRECIATION OF TANKS ($/YEAR)	DEP_{IST}	3000.
DEPRECIATION OF TRUCKS ($/YEAR)	DEP_{TRAN}	0.

APPENDIX M

SPILLS OF OILY MATERIAL TO BALTIMORE HARBOR

Table 93. SPILLS OF OILY MATERIAL TO BALTIMORE HARBOR

Date	Type of Oil	Approx. Oil Spilled	Approx. Oil Recovered
07-26-71	Thin waste	150 gals.	150 gals.
08-12-71	Lt. black	1,200 gals.	undetermined
09-17-71	Bunker C	150/200 gals.	150/200 gals.
09-27-71	Bunker C	50/100 gals.	50/100 gals.
10-14-71	#5 Heating	800 gals.	undertermined
11-05-71	Bunker C	400 gals.	400 gals.
11-15-71	Medium weight	100 gals.	90 gals.
12-20-71	#2 Heating	1,500 gals.	undertermined
12-28-71	Waste oil	30 gals.	30 gals.
01-03-72	Bunker C	50 gals.	50 gals.
01-04-72	#2 Diesel Fuel	50 gals.	50 gals.
01-17-72	#6 Heating	75 gals.	75 gals.
01-20-72	#6 Heating	10 gals.	10 gals.
01-24-72	Waste oil	undetermined	none
01-25-72	Bunker C	20 gals.	20 gals.
01-27-72	Waste oil	50 gals.	50 gals.
02-05-72	#2 Diesel Fuel	200 gals.	none
02-08-72	Waste oil	10 gals.	10 gals.
02-09-72	#6 Heating	50 gals.	50 gals.
02-17-72	Thin oil	10 gals.	10 gals.
02-18-72	#6 Heating	1 gal.	1 gal.
02-24-72	#4 Fuel oil	100/300 gals.	none
02-26-72	Bunker C	200 gals.	recovered by company
03-02-72	#2 Heating	300 gals.	none
03-07-72	Molassas	undetermined	none
03-08-72	#2 Heating	6,000 gals.	800 gals.
03-13-72	#2 Diesel fuel	3,500 gals.	3,500 gals.
03-15-72	Waste oil	100 gals.	100 gals.
03-16-72	Waste oil	200 gals.	200 gals.
03-28-72	Foam & Waste	100 gals.	100 gals.
03-29-72	Bunker C	100/200 gals.	recovered by company

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* From Maryland Port Authority

Table 93 (Continued). SPILLS OF OILY MATERIAL TO BALTIMORE HARBOR

Date	Type of Oil	Approx. Oil Spilled	Approx. Oil Recovered
04-04-72	#6 Heating	30 gals.	recovered by company
04-05-72	Waste oil	5 gals.	none
04-05-72	Waste oil	100 gals.	recovered by company
04-06-72	Oil & gasoline	6,000 gals.	none
04-10-72	#4 Heating	200 gals.	200 gals.
04-18-72	Waste	10/15 gals.	10/15 gals.
05-03-72	Waste	5 gals.	none
05-03-72	Bunker C	5 gals.	cleaned up by ship crew
05-07-72	Paraxylene	30 gals.	undetermined
05-08-72	#2 Fuel oil	10 gals.	cleaned up by company
05-09-72	Waste oil	5 gals.	5 gals.
05-10-72	Waste Oil	5 gals.	5 gals.
05-12-72	Bunker C	30 gals.	15 gals.
05-12-72	#2 Fuel oil	30/50 gals.	30/50 gals.
05-12-72	Bunker C	20/50 gals.	recovered by company
05-18-72	#4 Fuel oil	200 gals.	150 gals.
05-22-72	Bunker C	100 gals.	90 gals. + 6 tons debris
05-24-72	Waste oil	50 gals.	50 gals.
05-25-72	Light fuel oil	10 gals.	none
06-01-72	Gasoline	100 gals.	none
06-02-72	Hvy. used oil	25-50 gals.	none
06-06-72	Gasoline	5,700 gals.	none
06-14-72	Waste oil	30 gals.	30 gals.
06-14-72	Bunker C	50 gals.	cleaned up by company
06-14-72	Paint product	- - -	- - -
06-15-72	Fuel oil	50 gals.	none
06-20-72	#2 Fuel oil	25 gals.	none
06-27-72	Waste oil	- - -	- - -
07- -72	Detergent	undetermined	cleaned up by company
07- -72	#5 Fuel oil	3,000 gals.	2,300 gals.
07- -72	Waste oil	- - -	- - -
07- -72	Waste oil	750 gals.	250 gals.
07- -72	#2 Fuel oil	500 gals.	none
07- -72	#2 & #6 oil	50 gals.	25 gals.
07- -72	White liquid	10 gals.	none
08-12-72	Gasoline	50 gals.	none
08-24-72	Asphalt	4,000 gals.	cleaned up by company
08-28-72	Bunker C	30 gals.	cleaned up by company
08-30-72	Light waste oil	small traces	none
08-31-72	Waste oil	small traces	none

Table 93 (Continued). SPILLS OF OILY MATERIAL TO BALTIMORE HARBOR

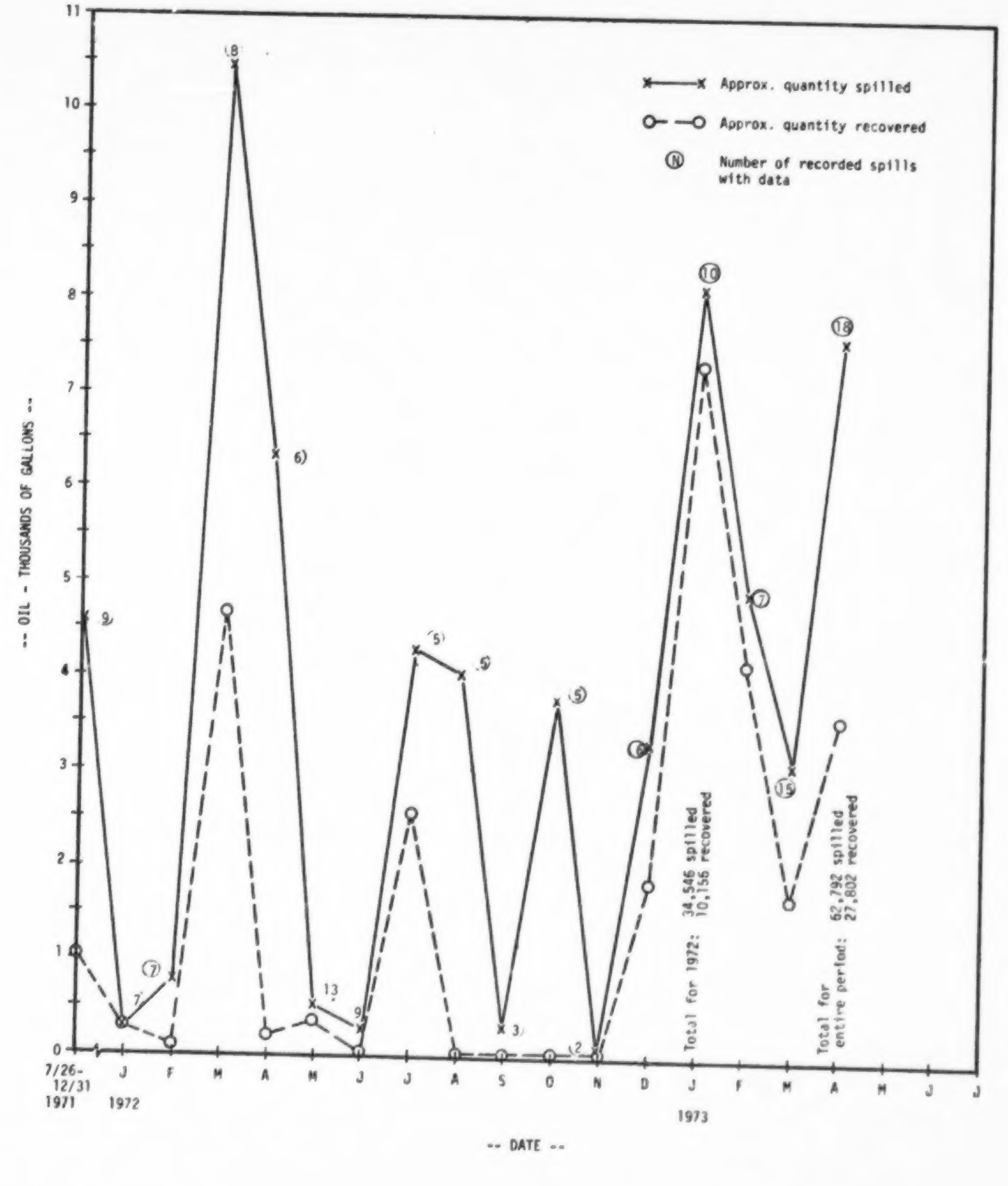
Date	Type of Oil	Approx. Oil Spilled	Approx. Oil Recovered
09-19-72	Unknown	50 gals.	25 gals.
09-22-72	Waste oil	undetermined	5 gals.
09-26-72	Fuel oil	265 gals.	none
09-28-72	Bunker C	30 gals.	cleaned up by vessel's crew
10-02-72	#6 Heating	20 gals.	none
10-03-72	Gasoline	3,000 gals.	none
10-17-72	Waste oil	30 gals.	20 gals.
10-24-72	Waste oil	10 gals.	none
10-27-72	Diesel oil	700 gals.	none
11- -72	Asphalt	20 gals.	15 gals.
11- -72	Bunker C	50 gals.	25 gals.
11- -72	#5 Heating	undetermined	cleaned up by USCG
12-02-72	#2 Fuel	900 gals.	none
12-05-72	#4 Fuel	150 gals.	125 gals.
12-06-72	Diesel fuel	200 gals.	150 gals.
12-06-72	#6 Bunker fuel	100 gals.	75 gals.
12-14-72	#15 Intermediate	2,000 gals.	1,500 gals.
12-29-72	#5 Heating	10 gals.	5 gals.
01-08-73	Waste oil	150 gals.	125 gals.
01-09-73	Waste oil	25 gals.	none
01-10-73	Bunker C	6,500 gals.	6,000 gals.
01-10-73	Bunker C	100 gals.	50 gals.
01-10-73	Waste oil	1,200 gals.	1,000 gals.
01-10-73	Waste oil	5 gals.	none
01-11-73	Soluble oil	10 gals.	none
01-17-73	Bunker C	5 gals.	none
01-24-73	#2 Fuel	100 gals.	100 gals. (by company)
01-30-73	Bunker C	30 gals.	30 gals. (by company)
02-03-73	#2 Fuel	400 gals.	300 gals.
02-07-73	#6 Fuel	4,000 gals.	3,500 gals.
02-15-73	Asphalt	400 gals.	300 gals.
02-20-73	#6 Low sulfur	42 gals.	42 gals.
02-21-73	#6 Fuel	25 gals.	none
02-23-73	#2 Fuel	10 gals.	none
02-27-73	Gasoline & #2 Fuel	10 gals.	none
03-01-73	#2 Fuel	600 gals.	500 gals.
03-05-73	Bunker C	5 gals.	none
03-05-73	Heavy oil	50 gals.	50 gals.

Table 93 (Continued). SPILLS OF OILY MATERIAL TO BALTIMORE HARBOR

Date	Type of Oil	Approx. Oil Spilled	Approx. Oil Recovered
03-06-73	#2 Fuel	1,800 gals.	700 gals.
03-08-73	Waste oil	10 gals.	none
03-09-73	Coal dust	- - -	- - -
03-12-73	Lube oil	30 gals.	15 gals.
03-13-73	Fuel oil	small amount	none
03-14-73	Blue liquid	20 gals.	none
03-16-73	Waste oil	20 gals.	20 gals.
03-16-73	Waste oil	250 gals.	250 gals.
03-18-73	#2 Fuel	100 gals.	none
03-22-73	Waste oil	200 gals.	150 gals.
03-25-73	Bunker C	15 gals.	none
03-30-73	Waste oil	10 gals.	none
04-01-73	Waste oil	20 gals.	5 gals.
04-01-73	#6 Oil	500 gals.	none
04-10-73	Waste oil	5 gals.	5 gals.
04-11-73	Transmission oil	100 gals.	50 gals.
04-12-73	#4 Fuel	4 gals.	4 gals.
04-16-73	- - - Investigated - - - Could not find any oil - - -		
04-16-73	Waste oil	5 gals.	none
04-16-73	Waste oil	300 gals.	300 gals.
04-17-73	Waste oil	400 gals.	400 gals.
04-19-73	Paint product	60 gals.	60 gals.
04-23-73	Waste oil	10 gals.	none
04-23-73	Waste oil	20 gals.	none
04-23-73	#6 Heating	1,500 gals.	none
04-23-73		4,000 gals.	2,000 gals.
04-24-73	Oil & debris	200 gals.	200 gals.
04-25-73	Oil & debris	100 gals.	100 gals.
04-25-73	Diesel fuel	70 gals.	70 gals.
04-27-73	Waste oil	300 gals.	300 gals.

Figure 10. REPORTED OIL SPILL AND RECOVERY INCIDENTS

BALTIMORE HARBOR 7/26/71 - 4/27/73



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